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A Biogeochemical Study of Ditchplug and Natural Pools in Sprague River Marsh, Phippsburg, ME

Ingrid Knowles
Bates College, iknowles@bates.edu

A Biogeochemical Study of Ditchplug and Natural Pools in the Sprague River Marsh, Phippsburg, ME

A Thesis

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By
Ingrid Bischoff Knowles

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Abstract

Many of the marshes in New England currently have a network of small, hand-dug ditches (put into place by the first European settlers 300+ years ago). Ditches drain the marsh during the ebb tidal cycle. In an effort to restore these ditched marshes and increase the pool habitat, U.S. Fish and Wildlife Service has plugged eleven ditches in the southern end of the Sprague River Marsh in Phippsburg, ME, beginning in the early 2000s. Few studies have been done to monitor the changes after restoration. The purpose of this research is to study the biogeochemical cycling of ditchplug and natural pools. In the summer of 2010 mummichogs (*Fundulus heteroclitus*), surface sediment, vegetation, biomass cores, and other marine organisms were collected for stable isotope analysis. General water quality parameters were also monitored along with the collection of nutrient data (NO_3^-, PO_4, and NH_4). Extraction of 2007 LiDAR data was used to observe changes in elevation across the marsh to show shifts in surface vegetation cover. Results suggested enrichment in ^{13}C in the muscle tissue from the mummichogs collected in the ditchplugged pools. These trends were likely due to differences in vegetation type between the natural and ditchplugged areas of the marsh. These vegetation differences were thought to be driven by differences in elevation, salinity, and hydroperiod between the two study areas. The POM in the ditchplug area was also enriched in ^{13}C relative to the natural pools. This was thought to be from different carbon sources or increased rates of primary production in the ditchplug pools relative to the natural pools. Further work is needed to understand carbon sourcing in the two systems in order to gain a better understanding of the biogeochemical cycling.

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Introduction

1.1 Maine Coastline

The coast of Maine is divided into four different sections (Figure 1.1). The geology influences the morphology of the coastline, thus influencing the different types of salt marshes that form. The southern coast of Maine lies within the Arcuate Embayment division of the coastline (Figure 1.1) (Kelley *et al.*, 1988). It is 504 km in length and contains 26.4 km^2 of measured marsh. The most common type of marsh in this area is back barrier, the largest and most common marsh type in Maine (Kelley *et al.*, 1988).

The Indented Shoreline division stretches from Portland to Penobscot Bay (Figure 1.1). The Indented Shoreline is about 1636 km in length and has a marsh area of 27.4 km^2. It is characterized by highly metamorphosed rock and many elongated peninsulas. The most common marsh formation within this compartment is the fluvial marsh. Fluvial marshes differ from back barrier marshes in the fact that the salt marsh hay, *Spartina patens*, grades into *Spartina alterniflora* and mudflats rather than sandy beaches (Kelley *et al.*, 1988).

The largest division of the shoreline is the Island-Bay Complex (Figure 1.1). This extends from Penobscot Bay to Machais Bay and consists of large exposed embayments. It is 2462 km in length and has a marsh area of 20.6 km^2. The granitic islands serve as protection from wave energy, thus offsetting the interface between deposition and erosion necessary for salt marsh formation (Kelley *et al.*, 1988). Therefore, many mud flats, coarse-grained flats, and exposed rock are found in this area.

Cliffed Shoreline extends from Machias Bay to the Canadian border (Figure 1.1). This compartment is about 681 km in length and has a marsh area of 4.5 km^2. There are some salt marshes present; however mud flats and exposed rock are more common in this region (Kelley *et al.*, 1988).

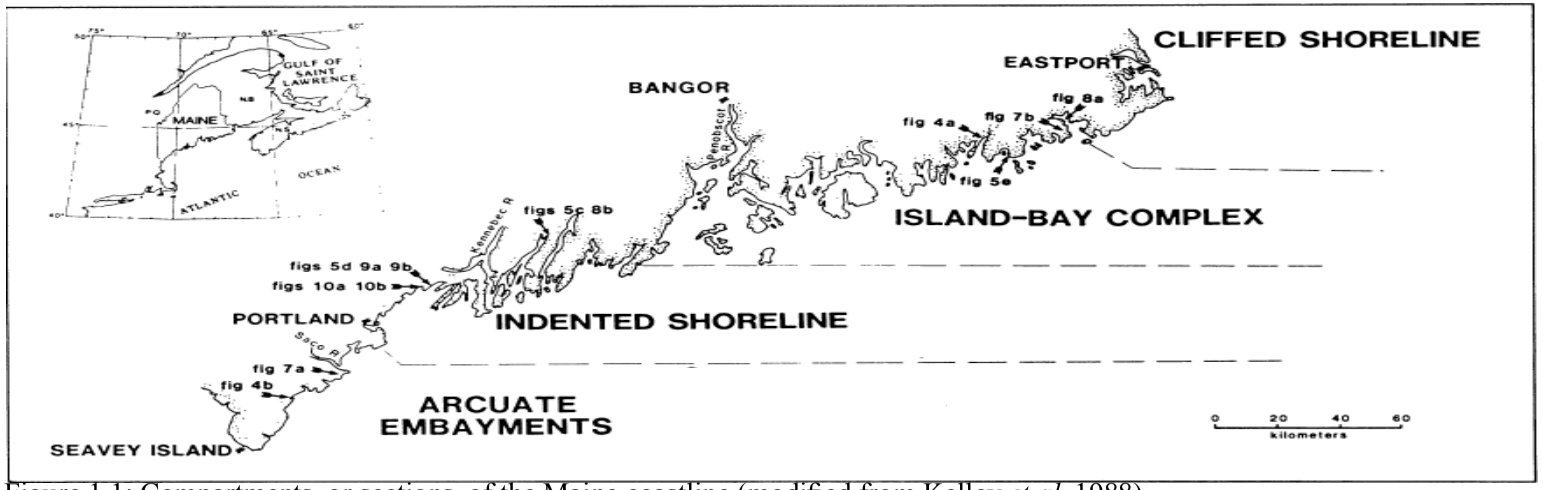

Figure 1.1: Compartments, or sections, of the Maine coastline (modified from Kelley *et al.*,1988)

1.2 Salt Marshes

1.2.1 Glacial History

Late Quaternary relative sea level in Maine has been controlled by the complex interactions between isostatic rebound and eustatic sea level rise (Figure 1.2). Approximately 12,000 years ago, sea level was at its maximum. No ice was present and the land was depressed due to glacial isostatic depression. This period marks the deposition of the Presumpscot Formation, a fine grained glaciomarine sediment. Since there was no ice present, the land began to rebound, driving sea level lower. At about 9,000 years BP, sea level was about 60 meters lower than present. At 8,000 years BP eustatic sea level rise exceeded isostatic rebound and relative sea level began to rise again. At 4,000 BP, this eustatic sea level rise began to slow to current rates of sea level rise. 4,000 BP marks a period when salt marshes began to form through deposition from the eroding bluffs of the Presumpscot Formation (Kelley *et al.*, 1988).

1.2.2 Formation and Survival

Salt marsh plants inhabit the interfacial zone of fresh water and marine water systems. The tides drive changes in vegetation through the influence of either too much salt water or too much fresh water, both resulting in shifts in vegetation and ultimately marsh loss. The formation and survival of a salt marsh is dependent on the balance between sedimentation, subsidence, sea level rise, and decomposition (Silvestri & Marani, 2004). Once the vegetation becomes rooted in the accumulated sediment it acts as a sediment trap and marsh vegetation can expand and grow (Adamowicz, 2010). If subsidence or decomposition outpace deposition then the marsh will start to retreat and eventually result in a loss of marsh vegetation (Adam *et al*., 2008). Gulf of Maine salt marshes are thought to have formed about 4,000 years ago when relative sea level rise and marsh accretion were in balance (Figure 1.2).

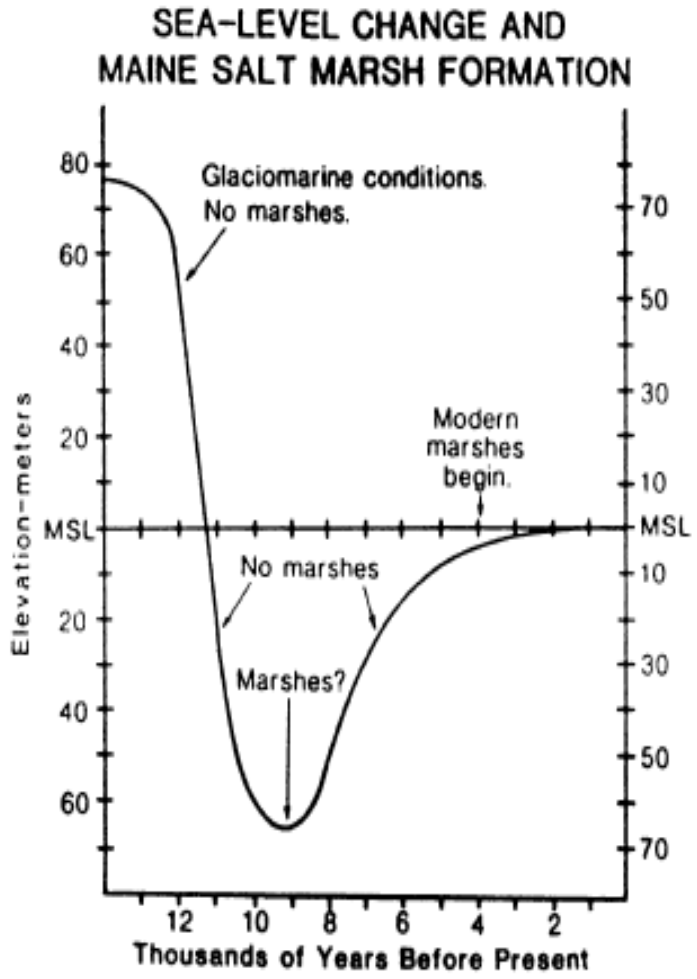

Figure 1.2: Relative sea level rise in Maine (modified from Belknap *et al.*, 1987).

1.2.3 Vegetation Zonation

There are distinct divisions (low marsh, high marsh, and higher high marsh) within marsh morphology driven by elevation shifts (Figure 1.3). These changes in elevation across the marsh determine vegetation type due to salt-tolerance and tidal inundation time. Low marsh is closest to the river channel, high marsh is between the low and higher higher marsh, and higher high marsh is the marsh boundary to the uplands. Vegetation in these areas is determined by tidal inundation time (hydroperiod). The vegetation is the low marsh is inundated with marine water for a longer period of time than the vegetation in the higher high marsh, thus different vegetation types are observed. Typical vegetation found in the low marsh on a New England marsh is the tall form of *Spartina alterniflora*. The high marsh is typically vegetated by the short form of *Spartina alterniflora*, *Spartina patens*, and *Distchilis spicata*. The higher high marsh is predominately vegetated by *Juncus gerardii* and sedges such as *Schoenoplectus robustus*. Along with the dominant plant species above, there are also multiple other plants on the marsh. Among these species are: *Atriplex patula*, *Limonium nashii*, and *Salicornia europaea*, typically found in high and higher high marsh areas of the marsh.

Vegetation on the marsh surface is constantly influenced by the hydroperiod, salinity, elevation, storms, nutrient supply, and oxygen supply (Niering & Warren, 1980). Vegetation competition is mainly seen on the high marsh where multiple factors other than hydroperiod influence vegetation type such as, salinity and soil oxygen (Niering & Warren, 1980). Typical vegetation for the high marsh environment in New England are *Spartina patens* and *Spartina alterniflora*.

1.2.4 Importance

Salt marshes provide many important ecosystem services, such as filtering out pollutants, sequestering carbon, and serving as storm surge protection (Aspden *et al.*, 2004). Additionally, the high productivity of salt marsh grasses support life for a diverse

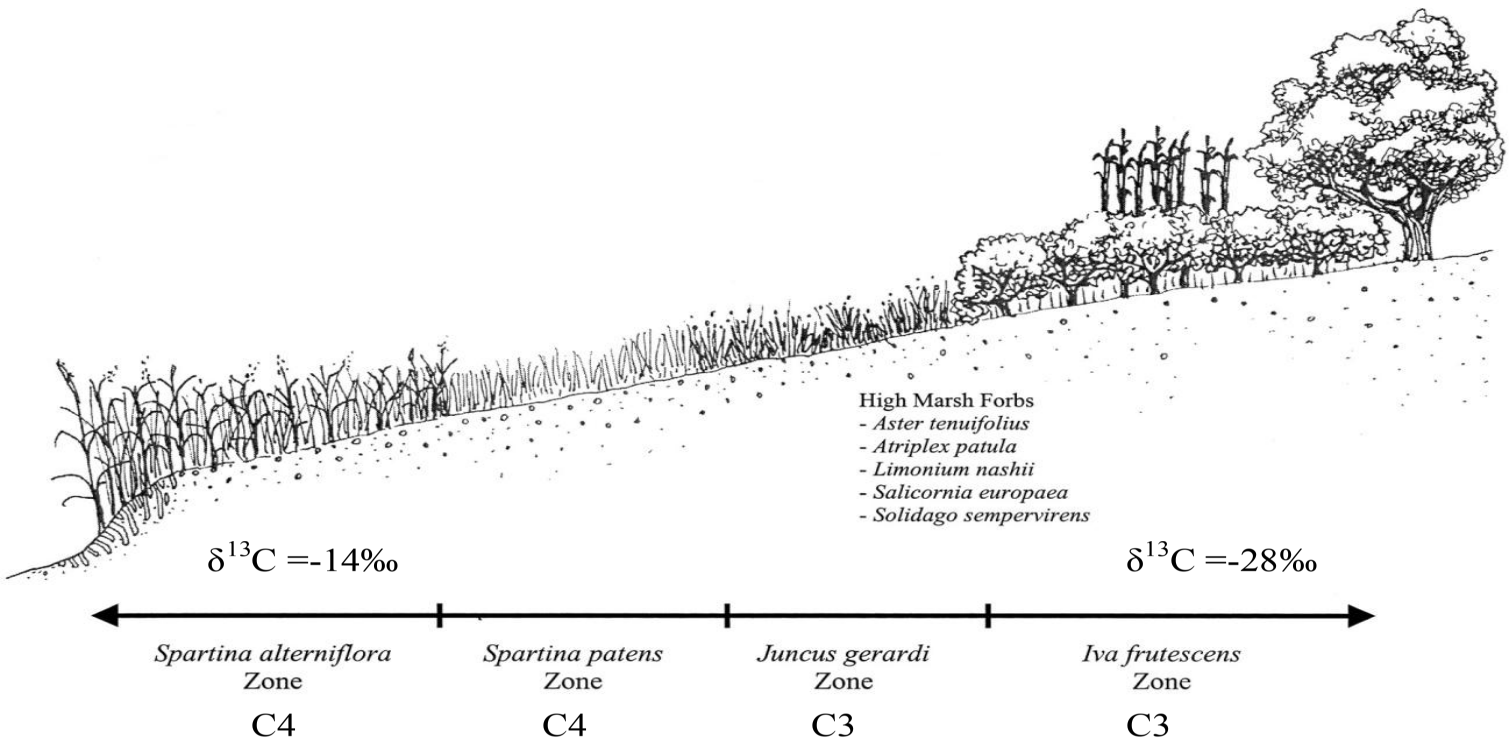

Figure 1.3: Cross section show transition in vegetation and elevation across a marsh (Bertness et al.,2002). $\delta^{13}C$ of plants and soils grades from pure C4 closest to the tidal channel to pure C3 farthest from the channel. The $\delta^{13}C$ values for C3 and C4 vegetation are from O'Leary (1988).

number of organisms, including fish, shrimp, oysters, mussels, and other invertebrates, thus, they have been called by many as nurseries of the ocean (Beck *et al.*, 2003).

1.2.5 Ditching

People have recognized the utility of salt marshes for centuries and have modified them in a variety of ways. Ditching is a very common form of human alteration that is seen on more than 90% of the salt marshes in New England (Kennish, 2001). Ditching was done initially to increase salt marsh hay production thereby providing food for livestock. Subsequent ditching effects have in fact lowered the mosquito population; however they have also physically altered areas of the marsh (Kennish, 2001). During high tides, the marsh will flood more than usual enabling the low marsh habitat to expand at the expense of high marsh environment (Kennish, 2001). Depending on how the ditching was done, it is possible that levees have formed, thus restricting tidal flow on parts of the marsh, influencing sedimentation and vegetation growth (Kennish, 2001). Ditching also can lower the salinity of marsh soil through the lowering of the water table (Adamowicz & Roman, 2002), therefore introducing invasive species such as *Phragmites* to grow over native *Spartina* (Koch & Gobler, 2009). Since the ditches can drain water in pools on the marsh, ditching can limit the habitat for many of the juvenile fish species as well (Koch & Gobler, 2009). Overall ditching can inhibit a marsh's ability to perform certain functions such as supporting salt marsh vegetation, habitat, and secondary consumers (Burdick *et al.*, 1997).

1.2.6 Salt Marsh Restoration

Multiple different types of salt marsh restoration techniques are generally used to restore natural surface water hydrology or to remove tidal restrictions (Adamowicz, 2010; Adamowicz & Roman, 2002; Burdick *et al.*, 1997; Bohlen, manuscript in prep). Culvert replacement is designed to widen natural tidal channels in marshes that have been built over. In such tidally restricted sections of a marsh, the vegetation can change and fish

habitat can diminish (Burdick *et al.*, 1997). Another technique used to increase tidal flow is a self-regulating tide gate. This is controlled by a buoy that hits a programmed high water level and releases the gate to close, thus increasing tidal flow (Adamowicz, 2010).

Open marsh water management (OMWM) is a new technique used to reduce mosquito habitat by widening ditches but still allows for water to flood the marsh so that fish will come onto the marsh and eat the bugs (Adamowicz, 2010). This method is much more localized and doesn't drain pools and pannes on the marsh, making it much less damaging than ditching (Kennish, 2001). It creates pannes on the marsh through enlargement and plugging of ditches in order to create levees to flood the marsh surface (MacKenzie & Dionne, 2007).

Seen in more urban areas, dredge spoil removal is a restoration technique that is used to level out a marsh that has been a recipient of dredge spoils from urban development or dredging of river channels. Some effects of dredge spoil restoration are extreme peat compression, subsidence, and death of marsh life (Adamowicz, 2010). Techniques are also used to reduce the growth of invasive species. These include salinity controls, tidal flow (channel construction), herbicides, and uprooting.

More recently, there has been a shift towards using techniques that will help marshes in their resilience against global climate change, particularly sea level rise. One way to prevent the erosional effects of rising sea level to marshes is through hard stabilization. This could be done by using rip-rap or other man-made products that reinforce shorelines. Another cause for marsh erosion is from wave energy. This can be prevented by planting oyster reefs in the river channel, which take much of the shock from wave energy.

1.2.7 Monitoring Restoration

Monitoring the progress of the ecosystem after the restoration project is imperative in order to measure the project's success (Adamowicz, 2010). One of the major issues with these restoration efforts are the problems with evaluating the

restoration project due to lack of funding for monitoring projects or controversy over the question of what makes a healthy marsh (Adamowicz, 2010; Adamowicz & Roman, 2002). Many projects have been conducted in monitoring restoration projects, yet have been inconclusive (Konisky *et al.,* 2006; Adamowicz & Roman, 2002). Konisky *et al.,* (2006) studied restoration on the regional level and although each marsh demonstrated successful restoration, there wasn't enough data to comprehend restoration success on a regional scale.

The Society of Ecological Restoration International recently released, in 2004, a set of nine guidelines that should be used to measure restoration success. Monitoring all nine aspects of a restoration project would ideally provide a thorough investigation into the effectiveness of the project; however, it comes down to lack of funding (Ruiz-Jaen & Aide, 2005). Due to the lack of funding, the most popular parameters studied are: diversity; vegetation structure; and ecological processes (Ruiz-Jaen & Aide, 2005; MacKenzie & Dionne, 2008). This type of monitoring can include water quality collection, surveying, vegetation mapping, and other common monitoring practices. These methods may be common in practice; however, Adamowicz & Roman (2002) noted a lack of quantitative analysis of marsh responses to restoration, in particular ditchplug restoration. Here in lies a very important area of research.

A study done by MacKenzie & Dionne (2008) tested if growth rates and secondary production of mummichogs were hindered by restriction of the pool environment; thereby testing ecological processes in restoration. Enclosures were placed at the pools and a control area was present where the fish had free access to the marsh and the pools. They found that access to the marsh surface was beneficial to both fish diets and growth rates (MacKenzie & Dionne, 2008). They also found that vegetated *Spartina patens* high marsh areas also play a role in a marsh fish life cycle, thus fish production (MacKenzie & Dionne, 2008). Another study done by Adamowicz & Roman (2002) found through GIS and aerial photography that ditchplug restoration does in fact increase

the water table on the marsh. The most noted difference in this study was the shift from high marsh vegetation (e.g. *Spartina patens*) to low marsh vegetation (e.g. *Spartina alterniflora*) (Adamowicz & Roman, 2002). Adamowicz & Roman (2002) suggest a long term monitoring plan, all dependent on the proper funding for the project.

1.3 Water Quality

General water quality parameters [temperature (ºC), dissolved oxygen (DO) (mg/L), specific conductivity (SpC) (mS/cm), and pH] are important to measure in order to gain a better understanding of the overall health of the water being studied. Temperature has a major influence on biological activity within a body of water (USGS, 2010). Higher temperatures result in higher productivity unless temperatures get too high in which case everything dies. DO concentrations can determine whether or not a body of water can support aerobic life. If there is no DO then the water cannot support aerobic life. Waters can become anoxic if respiration rates are high (USGS, 2010). SpC is a measure of the ability of water to conduct an electric current, a indicator of the number of ions present in solution and therefore a good measure for salinity. pH measures how acidic or basic water is on a scale from 0-14, 7 being neutral. Changes in pH result from the utilization of CO_2 and HCO_3^- by microflora in the water column and surface sediment (Pomeroy & Imberger, 1981). pH is also influenced by the presence of organic acids from decomposing organic matter. These general water quality parameters give a baseline for overall health of the water body supporting life on the marsh.

1.4 Stable Isotopes

Nitrogen and carbon isotopes have the potential to provide useful information on the functioning of ditchplug and natural pools on a salt marsh. Stable isotopes are used to create food web relationships within a specific environmental system. The isotopic composition of an organism's diet is represented by the isotopic composition of the organism itself with some isotopic offset between the diet and the consumer's tissues

(Sharp, 2007; DeNiro & Epstein, 1981). This isotopic offset is due to fractionation during respiration, assimilation, or metabolic fractionation during synthesis of different tissues (Michener & Kaufman, 2007; Peterson & Fry, 1987). Typically there is little fractionation between the source of an animal's diet and its carbon isotopic signature (~ 1‰) (Michener & Kaufman, 2007; Sharp, 2007; Peterson & Fry, 1987). Nitrogen isotopes, however are 3-4‰ enriched in animal tissue relative to the diet (Michener & Kaufman, 2007; Sharp, 2007). Thus, the nitrogen isotopic signature are very useful for determining trophic level of an organism. When only two isotopically distinct dietary sources are present, a two-end-member mixing model can be used to determine the relative importance of each to the diet. When more than two isotopically distinct food sources are present dietary information can be obscured using only one isotope. For this reason multiple isotope analyses are typically done to determine diets and food web relationships.

Different animal tissues are synthesized at different rates; therefore different tissues represent the animal's diet on different time scales (Sweeting *et al.,* 2007; Phillips & Eldridge, 2006; Tieszen *et al.,* 1983). For instance, liver tissue provides a short-term indicator of the diet (1-2 weeks) due to a more metabolically active tissue in comparison to the muscle tissue, which provides a longer-term signal of diet (several weeks) (Logan *et al.,*2005; Tieszan *et al.,* 1983). Muscle is more enriched in the heavy isotope of carbon relative to the liver signal due to the presence of isotopically depleted lipids in the liver (Michener & Kaufman, 2007; Tieszen *et al.,* 1983).

1.4.1 C3 and C4 Vegetation

On the salt marsh, plants utilize one of two photosynthetic pathways, which fractionate against $^{13}CO_2$ to varying degrees. C3 plants photosynthesize through the Calvin Cycle and C4 plants use the Hatch-Slack metabolic process (O'Leary, 1988). The initial fractionation is from diffusion of CO_2 through the stomata. This fractionation is small; a larger fraction is seen with different enzyme catalyzed reactions within the

plant's structure (O'Leary, 1988). C3 plants have an average $\delta^{13}C$ value of -28‰ and C4 plants have an average $\delta^{13}C$ value of -14‰ (O'Leary, 1988). Due to differences in photosynthetic pathways, C3 plants select against $^{13}CO_2$, thus having a more depleted $\delta^{13}C$ value.

On a global scale, the dominant form of plants is C3; however, the New England salt marsh environment is dominated by C4 vegetation, transitioning to C3 vegetation along the marsh margins (Figure 1.3). This vegetation shift reflects a shift in isotopic composition as seen in many diets studied of *Fundulus .heteroclitus* on marshes (Judice, 2010; Wozniak *et al.,* 2006; McMahon *et al.,* 2005; Mackenzie & Dionne, 2007). This shift is due to plant competition and the elevation of a salt marsh (Bertness *et al.,* 2002).

1.4.2 Previous Studies on Sprague Marsh

McMahon *et al.* (2005) combined gut content analysis and isotopic analysis of *Fundulus hereoclitus* at the Sprague Marsh and found that both dietary indicators revealed a strong C3 and C4 vegetation signal in the diet depending on where the fish were collected in the marsh. There are three major sources of food for mummichogs on the marsh, C4 vegetation, C3 vegetation, and phytoplankton (McMahon *et al.*, 2005). McMahon *et al.* (2005) focused on fish from North and South sections of the main tidal stream and investigated one pool and found that C3, C4, and phytoplankton were important to varying degrees. Phytoplankton, benthic micro and macroalgae, and epiphytic algae are other sources of carbon on the marsh.

In restoration ecology, the use of stable isotopes to gain a better understanding of the health of the restored ecosystem is a fairly new approach. However, isotopes are an important resource that can reveal information on nutrient cycling in the marsh. Recently, previous work using isotopes on Sprague River Marsh have been interesting, yet inconclusive. Judice (2010) found statistically significant isotopic differences in fish from ditchplug and natural pools, but had little replication at her sites. This study will determine how biogeochemical cycling in ditchplug pools and natural pools vary.

1.5 Purpose

The purpose of this study is to use stable isotopes, water quality, nutrient analyses, and grain size to study the biogeochemical cycling in three ditchplug and three natural pools on Sprague Marsh. Vegetation maps and surface elevation data will also be used to compare the two settings.

1.6 Study Area

1.6.1 Geology

The Sprague River Marsh is located in the Bates-Morse Mountain Conservation Area in Phippsburg, Maine at 43º45'N/69 º 50'W (Figure 1.4). Sprague Marsh is a back barrier marsh located south of Sewall Beach (Kelley *et al.*, 1988). It is approximately 2 km in length and 800 m wide adjacent to the southern section of the marsh (Johnson *et al.*, 2007; McMahon *et al.*, 2005). The marsh is formed in a glacially carved valley bordered by metasedimentary bedrock formations. According to the Maine Geological Survey, the Sprague Marsh is surrounded by the Cape Elizabeth formation (Hussey & Berry, 2008). An unpublished senior thesis performed a more in depth analysis of this area, showing that the marsh was surrounded by the Scarboro and Diamond Island formations (Covill, 1980) as well as the Cape Elizabeth Formation. These formations are all Ordovician to Devonian in age (Covill, 1980).

The marsh is laterally bisected by the Sprague River, entering in the northern end and exiting out the southwest corner of the marsh. The average sedimentation rate of the marsh is approximately 0.07cm/year (Johnson *et al.*, 2007). Sedimentation results from accumulation of organic matter and fine sediments from the Presumpscot Formation (Johnson *et al*., 2007) as well as from tidal deposition and deposition of eroded bedrock (Beirne, 2005). Larger sedimentation events result from storm surges and astronomical

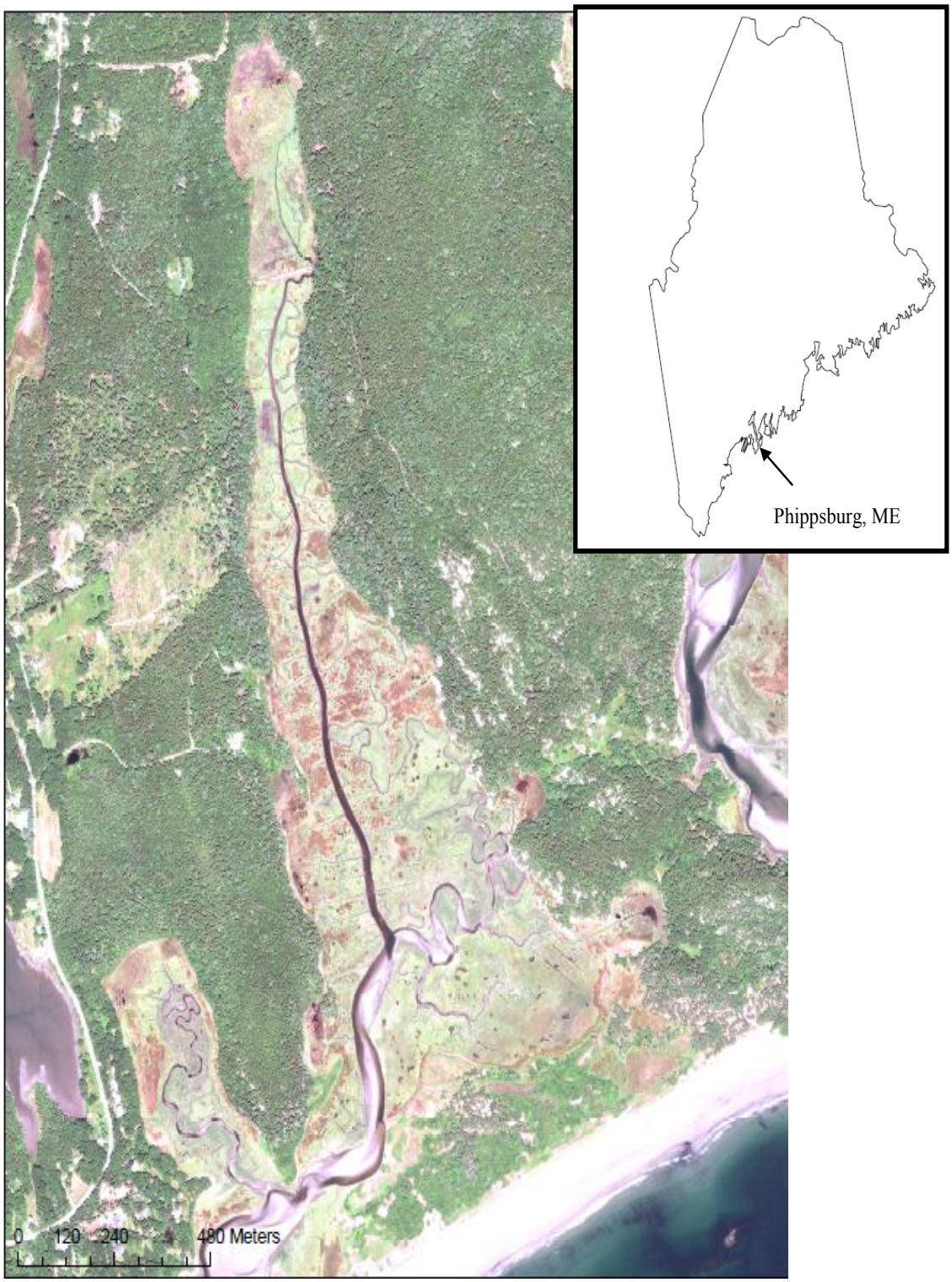

Figure 1.4 Location of Sprague River Marsh in Maine (July 31, 2010, Quickbird Image)

tides.

1.6.2 History of Human Alteration

Starting in 1716, the Sprague River Marsh has been influenced by human impact. During this time the Pejepscot Proprietors settled in what is now known as Small Point (Marden, J. Personal Communications, 2009 as cited by Judice, 2010). The marsh was highly valued land due to its high density of *Spartina patens* (a palatable grass/hay for livestock) known as salt marsh hay. The land on the marsh was divided between the first fifty families that settled in the area (Figure 1.5). The family plots were ditched perpendicular to the river channel in order to drain the surface of the marsh for grazing and cultivation of salt marsh hay. Along with draining for cultivation and grazing, it was also ditched with the idea of minimizing mosquito and greenhead fly populations in the area (Marden, J. Personal Commications, 2009 as cited by Judice, 2010).

The marsh was also impacted by causeway construction. Originally, it was a simple path across the marsh connecting the Bates-Morse Mountain Conservation area with Morse Mountain and Seawall Beach. During World War II, the United States Army built a radar tower at the top of Morse Mountain and installed a more substantial causeway to access the site.

In 1958 a landowner of the area, Junior Mellon, dredged and straightened the Sprague River channel to further reduce the mosquito and greenhead fly habitat (Marden, J. Personal Communications, 2009 as cited by Judice, 2010). This dredged channel is seen in air photos from the marsh today and provides a date for ditches that were dug after 1958, where any ditch perpendicular to Junior Mellon's channel was dug after 1958 (Marden, J. Personal Communications, 2009 as cited by Judice, 2010).

The major restoration projects on Sprague Marsh began in January of 2000. United States Wildlife and Fisheries Service (USFWS) in conjunction with Natural Resources Conservation Service (NRCS), The Nature Conservancy (TNC), and the Small Point Association originally planned to dredge around the perimeter of the northern

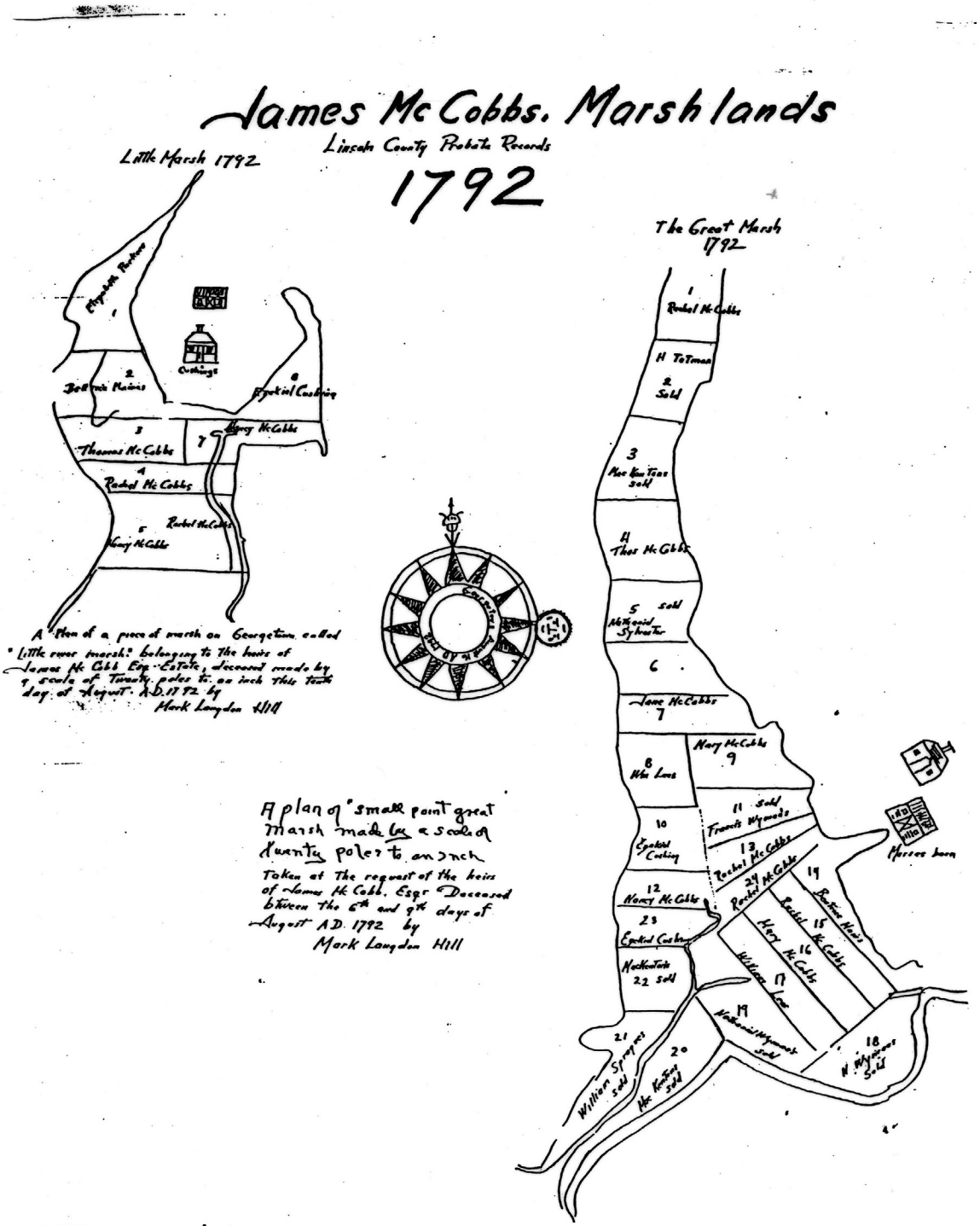

Figure 1.5: Map of family plots on Sprague Marsh in 1792 (Courtesy of Laura Sewall). Note that some of the ditches in the southern end of the marsh are still visible today.

section of the marsh to limit freshwater input and invasive plants (Marden, J. Personal Communications, 2009 as cited by Judice, 2010). After two days into the project, the marsh iced over and this part of the project was abandoned (Marden, J. Personal Communications, 2009 as cited by Judice, 2010). In 2002, the restoration efforts were pursued again and three ditches were plugged north of the causeway. The goal of the ditchplugging was to create pool habitat for bird and other wildlife species.

In the fall of 2002, the southern end of the marsh underwent ditchplug restoration by USFWS. Eleven ditchplugs were put in place, three close to the river channel and the other eight closer to the marsh boundary (Figure 1.6). At all eleven sites, two eight-foot pieces of plywood were driven into the marsh with a small excavator (Figure 1.7). Peat was then dug from the marsh surface and used to plug the space between the two pieces of plywood (Figure 1.8). The peat pulled from the marsh along with the ditch plug itself was done to create the additional pool habitat on the marsh surface.

In 2002, the river was dredged below the bridge of the causeway in hopes to restore tidal flow to the northern portion of the marsh. An excavator was brought onto the marsh to remove the hard stabilization underneath the bridge (Figure 1.9). The effects of this restoration were seen within hours. The peat from the river banks collapsed into the river channel due to a combination of marsh dewatering and increased tidal flow (Marden, J. Personal Communications, 2009 as cited by Judice, 2010) (Figure 1.10). To try to improve the poor tidal flow from the northern portion of the marsh, the culvert was widened and the bridge was replaced in April of 2006 (Marden, J. Personal Communications, 2009 as cited by Judice, 2010).

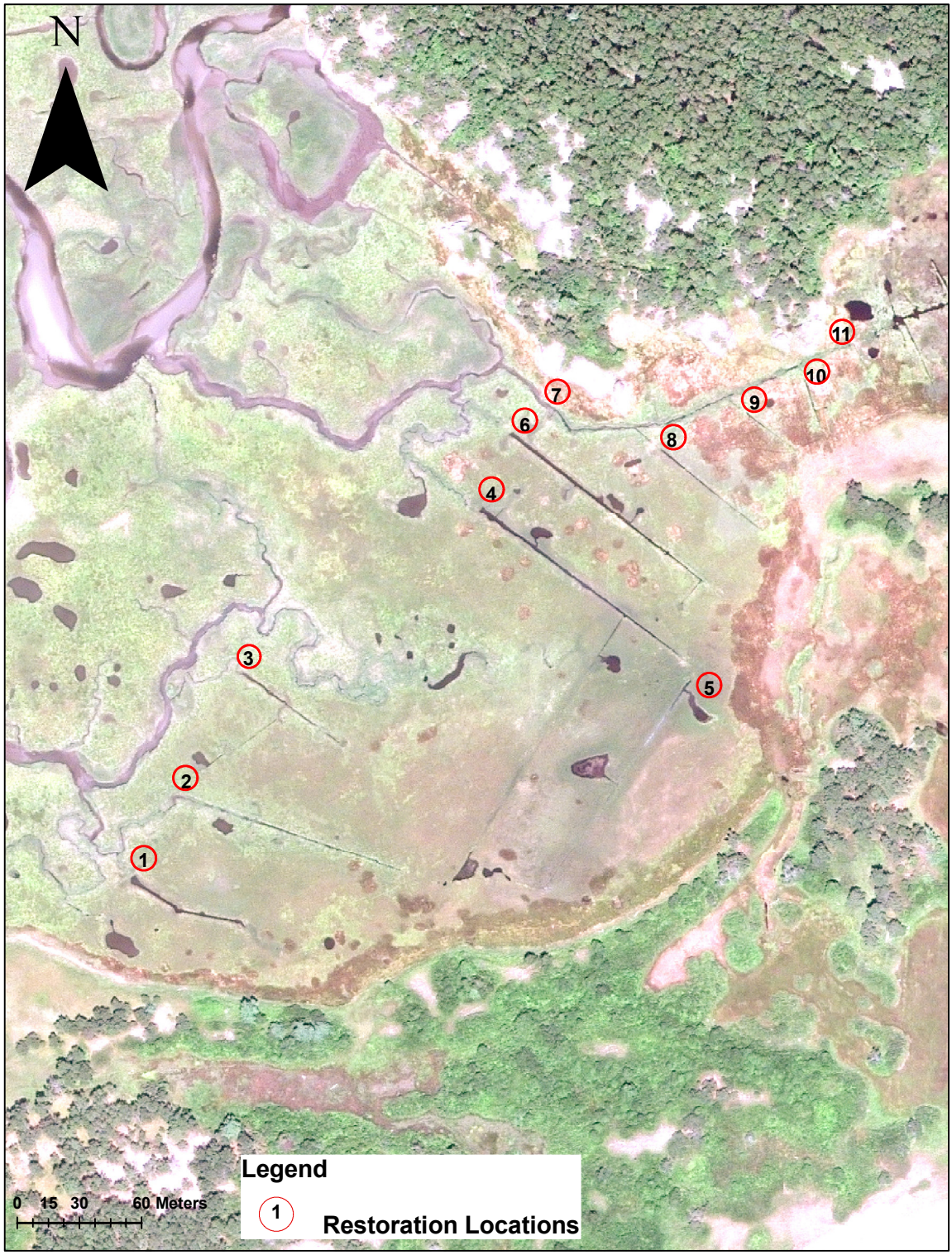

Figure 1.6: Quickbird satellite image (July 31, 2010) of the southern end of the Sprague Marsh showing the location of the eleven ditchplugs put in place in 2002 by USFWS

Figure 1.7: Photo showing plywood boards being inserted in the marsh during ditch plug restoration (Photo by Judy Marden).

Figure 1.8: Photo showing the excavator pulling up the peat on the marsh surface to be used to plug the ditch between the plywood boards (Photo by Judy Marden).

Figure 1.9: Photo showing the excavator removing the hard stabilization under the bridge of the causeway (Photo by Judy Marden)

Figure 1.10: Photo showing peat caving into the river channel after removal of the hard stabilization (Photo by Judy Marden)

Methods

2.1 Sample Collection and Preparation

2.1.1 Pool selection

Three natural and three ditchplug pools were selected for analysis in the Southern end of the marsh (Figure 2.1). The natural pools are representative of an area unaffected by ditch-plug restoration. The ditchplug pools have been altered by ditchplug restoration thus referred to as ditchplug.

The three natural pools are located close to the tidal river, Sprague River and are thought to flood daily during high tide. Site 1, is the most southern site and is about 40 meters from the dune system of Sewall Beach. Site 2, is located 200 meters north of Site 1. Site 3 is the northern most pool tested.

The three ditchplug pools are all located east of the major plug and close to the uplands (Figure 2.1). Site 4, is the largest pool located very close to the uplands. Site 5.2, is located very close to the major plug. The final ditchplug pool, Site 6, is also located close to the major plug, 11 meters from Site 5.2.

From each pool, water quality parameters (DO, SpC, temperature, pH), water samples (nutrients, chlorophyll-a, POM), mummichog (length, weight, isotopes on muscle and liver, gut contents), biomass cores, and sediment cores (grain size) were collected.

2.1.2 Water Quality

At each pool basic water quality measurements were taken using a Hydrolab. The following parameters were recorded: pH, dissolved oxygen (mg/L), specific conductivity (mS/cm), and temperature (˚C). Water quality was recorded during two sampling events, one in the the summer (June 28-30) and the other in the fall sampling of October 30th.

Site Locations

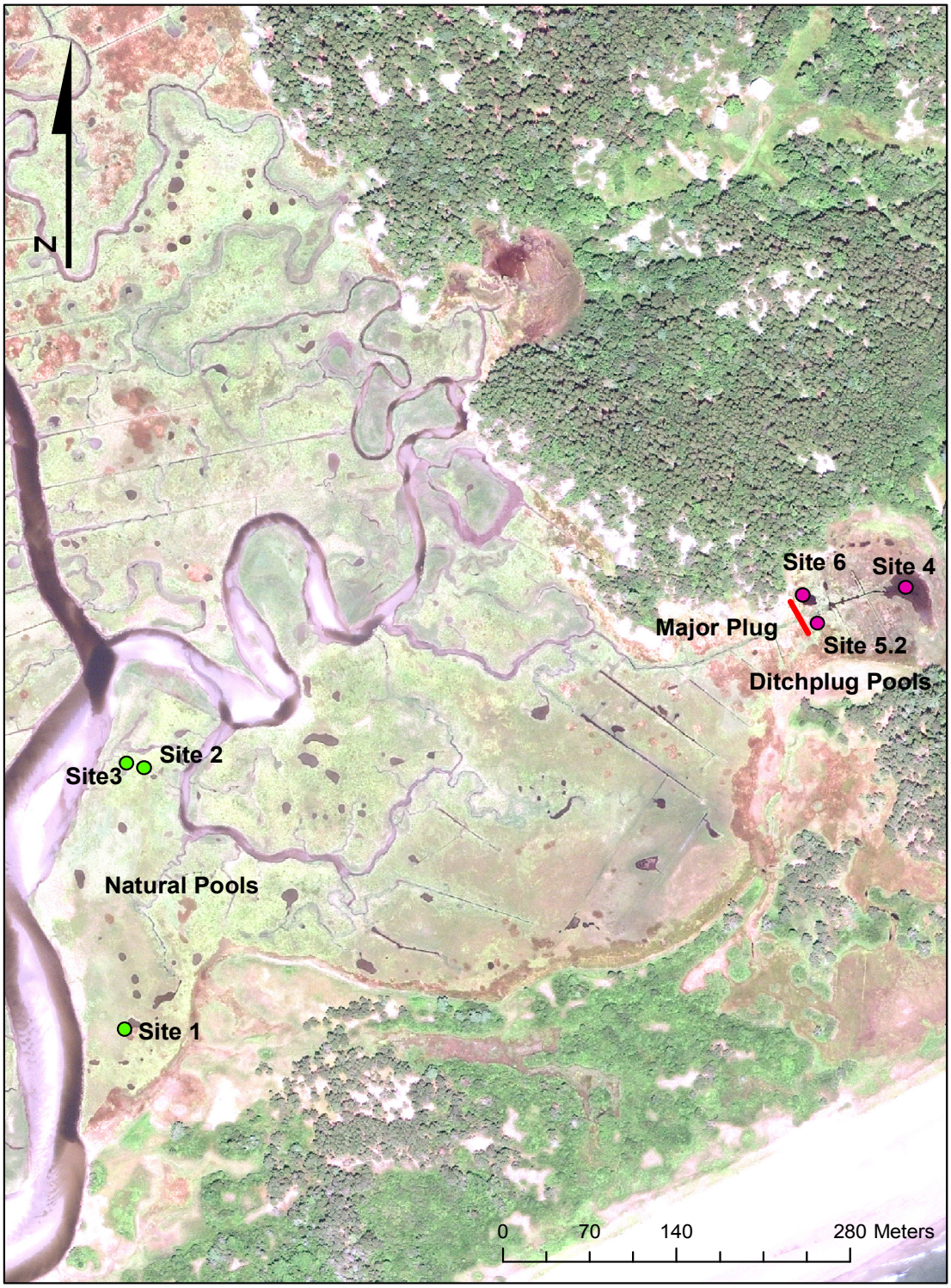

Figure 2.1: Location of field sites selected for sample collection on Sprague River Marsh, Phippsburg, ME. The green dots represent the natural pools, the pink dots represent the ditchplug pools, and the red line represents the major plug.

2.1.3 Water Samples

At each pool four liters of water were collected. Each liter of water was labeled and capped then placed on ice until they were placed in a refrigerator in the Environmental Geochemistry Lab at Bates College. A table recording all sampling and analysis of water can be seen in Table 2.1.

Along with the 4 L collected for own lab use, Northeast Laboratory out of Portland, ME was used for nutrient analysis. The water sent to the lab was unfiltered and filtered by NE lab. The NE lab was used for the summer samples to test for PO_4^{3-}, NO_3^-, and NH_4. NE lab had a detection limit of 0.2 uM for NH_4, 0.5 uM for NO_3^-, and 0.05 uM for PO_4^{3-}. Their protocol was followed for collection and sent to the lab. For the fall sampling, 100 mL was collected and filtered in the field in preparation to be sent to the Marine Science Lab at University of Maine at Orno. The samples were tested for nitrate, alkalinity, ammonia, and phosphorus. The detection limits used by the lab for nitrate was 0.30 uM. For alkalinity the detection limit was 0.13-0.45 uM. For ammonia the detection limit was 0.17 uM. The detection limit for phosphorus was 0.19 uM.

2.1.3.1 POM

The day of collection, the water was transported on ice back to the Environment Geochemistry lab at Bates College where it was filtered through a muffled Whatman® glass microfibre circular filter of 0.45 um. In the summer sampling season (June 28th-30th), 1 L of water was filtered. The filters were folded and placed in a freezer in aluminum foil. For the fall sampling, 500 mL of water was filtered. They were then freeze dried and prepped for stable isotope analysis. One quarter of the filter was placed in a tin cup and folded (Table 2.1). Only one sample was taken at each site because it was assumed to be homogeneous.

Sample Type	Summer Sampling	Fall Sampling	Sites	Filtered at Bates	Isotope Analysis	Analyzed
NE Lab	Y	N	1-6	N	N	Y
UMO Lab	N	Y	1-6	N	N	Y
3 L Chlorophyll	Y	Y	1-6	Y	N	N
1 L Seston	Y	Y	1-6	Y	Y	N
Sulfate	Y	Y	1-6	Y	N	N

Table 2.1: Methods of water samples collected in both the summer and fall sampling season. Y=yes. N=no.

2.1.3.2 Chlorophyll-a

Three liters of water collected from each pool were used for chlorophyll-a analysis. For the summer sampling, 1L was filtered through one filter, which was folded and placed in aluminum in the freezer until analysis. For the fall sampling, 500mL of sample were filtered through a muffled filter and preserved until analysis. 12 hours before analysis the filters were submerged in 10mL of 90% acetone in centrifuge tubes. They were kept in the freezer, covered in aluminum foil, until analysis 12 hours later (Table 2.1).

2.1.3.3 Sulfate

About 100mL of the water filtered for seston and chlorophyll-a analysis was saved for sulfate analysis. Sulfate analysis was done on a DR 2000 Spectrophotometer in the Environmental Geochemistry Lab at Bates College. Each pool was tested three times and averaged for a sulfate reading for each pool. Sulfate analysis was completed for both summer and fall samplings (Table 2.1).

2.1.4 Mummichog Collection

Both in the summer sampling (June 28th – 30th) and the fall sampling (October 30, 2010) mummichogs (*Fundulus heteroclitus*) were collected in every pool analyzed (Table 2.2). Standard minnow traps were set with chicken livers in cheesecloth as bait. The trap sat in each pool for about 20-45 minutes. Out of each trap, five of the largest male mummichogs were collected. If male mummichogs were not present, female mummichogs were collected. However, all data for the female mummichogs will not be discussed in this thesis. If other species were present, they were also collected. The maximum number of each type of fish caught was five; all other fish were returned to the same pool from which they were caught. Each fish kept was killed humanely and placed in sample bags, and placed on ice until they were brought to the lab.

Sampling Season	Sites	Stomach Contents	Isotope Analysis	Analyzed	Species	Number
Summer Sampling	1-6	Y	Y	Y	Male/Female Mummichog; Stickleback; Silverside	5; 5; 1
Fall Sampling	5.2	Y	Y	Y	Female Mummichog	5

Table 2.2: Fish species methods for all sites in both the summer and fall sampling. Y=yes. N=no. Note that site 5.2 was the only site where fish were found in the fall sampling.

All other organisms (e.g. macro and mircobenthic invertebrates) were collected using a scoop net. These organisms were placed in labeled sample bags and taken back to the lab freezer until further analysis.

2.1.4.1 Stomach Contents

The day the mummichogs were collected in the field they were brought back to the lab for stomach content analysis. The fish were weighed and the total length of each fish was measured and recorded. The weight of each stomach was also recorded. Percent vegetation and percent worm content within each stomach was determined by Jen Lindelof. This was done by placing the stomach contents on a petri dish with a grid. The contents were recorded by counting at the intersection of each line. Once stomach contents were removed the fish were placed back in their sample bag and placed in a freezer for up to 48 hours until stable isotope analysis.

2.1.4.2 Stable Isotope

Isotopic values are presented in a ratio of heavy to light isotopes relative to a standard (Hoefs, 2009; Sulzman, 2007). These values are expressed in parts per thousand or per mill (‰) deviation from a standard. The isotopic values are expressed in δ notation:

$$\delta = \frac{R(sample) - R(standard)}{R(sample)} \; x \; 1000$$

Where R is the ratio of heavy to the light isotope ($^{13}C/^{12}C$; $^{15}N/^{14}N$). A more positive δ value will reflect an isotopically enriched sample (more of the heavy isotope), as a more negative δ value will reflect an isotopically depleted sample (more of the light isotope). The standard for carbon is Pee Dee Belemnite (PBD) (0‰) and the standard for nitrogen is air (0‰). These are the internationally accepted standards for stable isotope analysis.

The fish were removed from the freezer and thawed before liver and muscle tissues were extracted and then freeze dried. Once freeze dried, the samples were then weighed out for bulk stable isotope analysis. A sample size of ranging between 0.2 mg and 0.9 mg was weighed out for the liver and muscle tissues. The weight was recorded and the samples were placed in tin cups and folded (Table 2.2).

2.1.5 Biomass Cores

To evaluate the epifauna, four biomass cores were collected using a plastic core tube 10 cm in diameter and submerged to 15 cm in sediment. Four biomass cores were collected at each site during the summer sampling (June 28-30) (Table 2.3). The tube had a green tape marked at 15 cm to set the depth for each core. The cores were taken randomly around each pool. The tube was pushed into the pool until the surface sediment was at the green tape. Cores were capped at the bottom by hand prior to removal, then transferred to a labeled bags. The cores were placed on ice until they were taken back to the lab where they were immediately sieved.

The biomass cores were sieved through a 500 micron sieve. The greater than 500 micron fraction was preserved in formalin dyed with Rose Bengal. Only three cores were sorted for macroinvertebrates, but none were identified. The sorting and macroinvertebrate identification was not further pursued in this study. The remaining biomass cores were preserved and stored for future analysis.

One core taken from each pool was sorted the day of collection for bulk stable isotope analysis of one Nereis worm from each core. The worms collected from the cores were freeze dried and prepared for bulk stable isotope analysis. A sample size of 0.3 mg to 0.9 mg was weighed out for the worm samples. The weight was recorded and the samples were placed in tin cups and folded (Table 2.3).

Sampling Season	Sites	Number	Sieved	Preserved	Sorted	Analyzed	Isotope Analysis
Summer (June-28-30)	1-6	4	Y	Y	Y*	N	Y**
Fall (October 30)	N	N	N	N	N	N	N

Table 2.3: Biomass core methods for summer and fall sampling. Number refers to the number collected from each pool during the sampling season. *The biomass cores from site 1 were the only ones processed for benthic invertebrates. **No worms were found in the core from site 4 for isotope analysis.

2.1.6 Surface Sediment

At each pool, a sediment sample was taken by hand of the first 3cm of sediment during the summer sampling (June 28th-30th). Three surface sediment samples were taken at random around each pool. Each sample was placed in individually labeled bags and taken back to the lab where they were placed in the freezer.

Once frozen, they were freeze dried. They were homogenized with a Spex mill and then weighed out for bulk stable isotope analysis. A sample size of 0.5 mg to 0.9 mg was weighed out for each sediment samples. The weight was recorded and the samples were placed in tin cups and folded.

2.1.7 Sediment Cores

On July 6, 2010 a sediment core was taken at each pool. The cores were taken at a random location within each pool in order to gain a better understanding of sediment distribution across the marsh. A tube was pushed into the sediment until it could not be pushed in any further. It was then capped, pulled up, and then capped at the bottom. The cores were labeled and placed on ice until carried back to the lab. Once in the lab they were drained and placed in a refrigerator until further analysis.

2.1.8 Plant Identification

Throughout the summer sampling (June 28th -30th) abundant marsh species were collected and identified using plant keys (Lamoureux, 1985; Dionne et al., Resource guide; Ursin, 1972) and reference collections (Berine, 2005). The plant samples were mapped using a GPS. On July 6, 2010 a Trimble GPS was used to map the major vegetation boundaries around the natural and ditchplug pool.

2.3 Analytical and Techniques

2.3.1 Nutrient Concentrations: UMO and NE Laboratories

The summer water samples were sent to Northeast Laboratories. For ammonia they used EPA method 350.1 (detection limit of 0.2 mg/L). For nitrate they used EPA method 9056 (detection limit of 0.5 mg/L). For phosphorus they used the method SM 4500 PE (detection limit of 0.05 mg/L). The detection limit for this laboratory was too high to detect any of the parameters in each sample so the data from this lab will no longer be discussed. Water samples from the fall sampling were sent to the Marine Science Lab at the University of Maine at Orno (Table 2.1).

2.3.2 Isotope-Ratio Mass Spectrometry

Bulk isotope analysis ($\delta^{15}N$ and $\delta^{13}C$) of muscle, liver, surface sediment, and seston was performed using a Costech Elemental Analyzer (EA) connected to a ThermoFinnigan Delta Plus Advantage Stable Isotope Ratio Mass Spectrometer (IRMS) via a Conflo III interface at the Environmental Geochemistry Laboratory, Department of Geology, Bates College. The accuracy and precision of the IRMS was determined by running a working standard (acetanilide: C_8H_9NO) analyzed nine times within each run. The reproducibility was ±0.2‰ for both $\delta^{15}N$ and $\delta^{13}C$.

2.3.3 ArcGIS Mapping

Data were downloaded from a Trimble GPS system and analyzed on ArcGIS. ArcGIS was used to ground truth satellite images for vegetation cover.

LiDAR data from 2007 (JALBTCX, 2011) was also analyzed using ArcGIS. The vertical data was extracted and elevation transects were established. These data were used to get elevation shifts across the marsh. There was a 0.2 m vertical accuracy with a 95% confidence level. (LiDAR scanning project, 2004)

2.3.5 Chlorophyll-a

The tubes containing the 90% acetone and a filter from a specific site were centrifuged for 5 minutes prior to analysis. A 1mL sample out of each tube was removed and placed into a glass test tube. Then 8mL of 90% acetone was added to the sample. The diluted sample was then placed into the 10-AU Fluorometer for analysis. The same tube was removed and 1 drop from an eyedropper of HCl was added to remove the pheopigments from the sample. It was then tested again for another reading. This was done on all the samples from the summer sampling from June 28th-30th, 2010 and for the samples collected in the fall on October 30, 2010.

2.3.6 Sediment Cores

Each sediment core was split using a Dremel electric hand saw. They were then core logged and stratigraphic images were constructed using SigmaPlot 11.0. The top 3cm of each core was sub sampled and placed in the freeze dryer. Once dried the dry weight was recorded for each sample. The organics were then digested in 30% H_2O_2. A wet sieve 40φ was used to determine the silt to sand boundary in each sample. The samples were dried in an oven for five days, the dry weight was recorded. The samples were then placed in a furnace to burn off the remaining organics for two hours at 450˚C, the weight of sample was then recorded.

2.4 Statistical Analysis

Two- tailed t-tests were used throughout to determine significant differences for mean water quality, isotopic, gut contents, seston, and cholorophyll-a variable between the natural and ditchplug sites. The statistical analysis was run on the program Minitab 16 Statistical Software. A p-value <0.05 was considered statistically significant.

Results

The isotopic data for *F. heteroclitius* (mummichogs), surface sediment, worms, particulate organic matter (POM), vegetation, and other marine organisms can be seen in Appendix A. Gut contents data for all fish that were collected in both in fall and summer sampling can be found in Appendix B. Core stratigraphy data can be found in Appendix C.

3.1 Mummichog Data

3.1.1 Male mummichog $\delta^{13}C$ and $\delta^{15}N$ of Muscle and Liver tissues

A two-tailed t-test indicated a statistically significant difference between the natural and ditchplug sites in $\delta\ ^{13}C$ of the muscle tissues ($p=0.039$) (Table 3.1). The $\delta^{13}C$ muscle tissue data from the natural sites were enriched in ^{13}C relative to the ditchplug sites (Figure 3.1). The average $\delta\ ^{13}C$ was -16.5‰ (±0.8‰) and -18.7‰ (±0.1‰) for the natural and ditchplug sites, respectively (Table 3.2).

A two-tailed t-test showed no statistical significance between the natural and ditchplug pools in $\delta\ ^{13}C$ of the liver tissues ($p=0.092$) (Table 3.1). The $\delta^{13}C$ for the liver tissues in the natural pools suggested enrichment relative to the ditchplug sites (Figure 3.2). The average $\delta^{13}C$ was -17.0‰ (±0.6‰) and -20.1‰ (±0.1‰) for the natural and ditchplug sites, respectively (Table 3.2).

A two-tailed t-test indicated no statistical significance between the natural and ditchplug pools for $\delta^{15}N$ of muscle tissue ($p=0.295$) (Table 3.1). The average $\delta^{15}N$ was 9.1‰ (±0.3‰) and 9.0‰ (±0.3‰) for the natural and ditchplug sites, respectively (Table 3.3) (Figure 3.1).

No statistical difference was found between the natural and ditchplug pools for $\delta^{15}N$ of liver tissues ($p=0.816$) (Table 3.1). The average $\delta^{15}N$ was 8.0‰ (±0.4‰) and 8.2‰ (±0.6‰) for the natural and ditchplug pools, respectively (Table 3.3) (Figure 3.2).

In this study a lipid extraction was not performed on the muscle or liver tissue. Because lipids are typically 2-8‰ depleted in ^{13}C relative to proteins, the more depleted

Comparison	Average (±SE Mean)	n	T-Value	p-value	DF
Muscle Tissue					
N $\delta^{13}C$ v. DP $\delta^{13}C$	N= -16.5 (0.4) DP= -18.7(0.1)	3;3	4.92	0.039	2
N $\delta^{15}N$ v. DP $\delta^{15}N$	N= 9.1 (0.1) DP= 9.0 (0.1)	3; 3	1.27	0.295	3
Liver Tissue					
N $\delta^{13}C$ v. DP $\delta^{13}C$	N= -17.0(0.4) DP= -20.1 (0.1)	2; 3	6.89	0.092	1
N δ^{15} N v. DP $\delta^{15}N$	N= 8.3 (0.2) DP= 8.2 (0.2)	2; 3	0.26	0.816	2

Table 3.1:Two-tailed t-test results for comparison of mummichog muscle and liver tissues of the natural (N) and ditchplug (DP) sites. n is the number of all the isotope runs for N; DP. DF is the degrees of freedom or the number of values in the final calculation that are free to vary. The T-value is the difference between the mean and average scores of the N and DP groups. p-value is a number expressing the probability of obtaining a test statistic as extreme as the one actually observed, a p-value of <0.05 was considered significant.

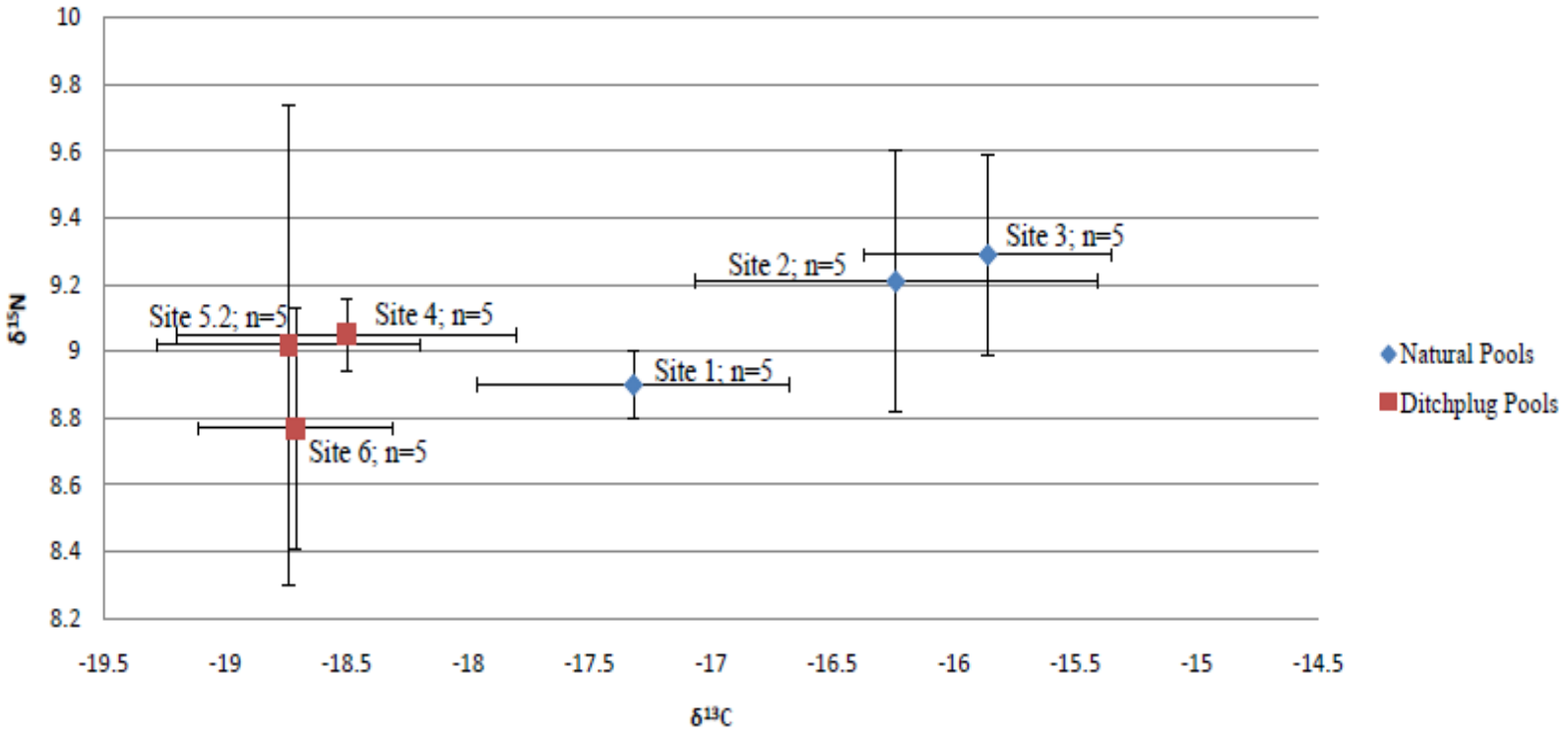

Figure 3.1: Dual isotope plot of average $\delta^{13}C$ and $\delta^{15}N$ values of male mummichog muscle tissue from six different pools. The error bars represent standard deviation.

Site	Average $\delta^{13}C$ Muscle (‰)	n	Stdev (‰)	Average $\delta^{13}C$ Liver (‰)	n	Std. Dev (‰)
1	-17.32	5	0.64	n/a	n/a	n/a
2	-16.24	5	0.83	-17.47	4	0.72
3	-15.86	5	0.51	-16.62	4	0.73
Average	**-16.47**			**-17.04**		
Std. Dev	**0.76**			**0.60**		
4	-18.50	5	0.70	-20.12	5	1.24
5.2	-18.74	3	0.54	-20.18	2	0.12
6	-18.71	4	0.40	-19.91	3	0.49
Average	**-18.65**			**-20.07**		
Std. Dev.	**0.13**			**0.15**		

Table 3.2: Average $\delta^{13}C$ of male mummichog muscle and liver tissue across the marsh at each site from the summer sampling.

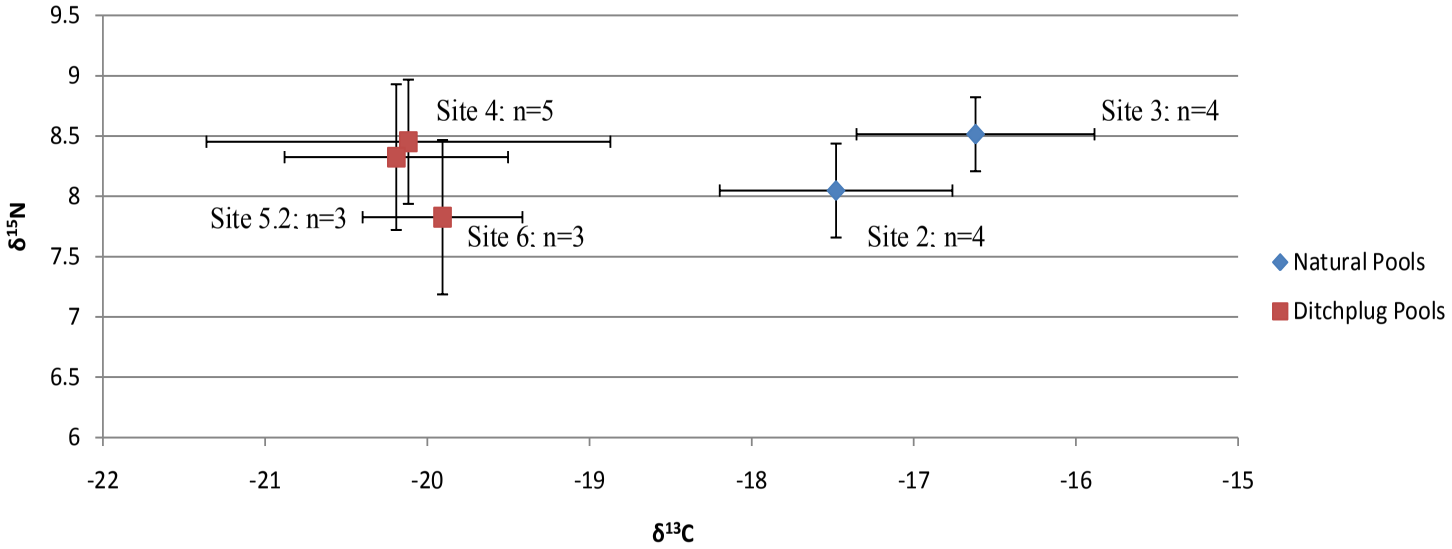

Figure 3.2: Dual isotope plot of average $\delta^{13}C$ and $\delta^{15}N$ values for liver tissue data from male mummichogs collected in the summer sampling. The error bars show standard deviation.

Site	Average $\delta^{15}N$ Muscle (‰)	Stdev (‰)	n	Average $\delta^{15}N$ Liver (‰)	Std. Dev (‰)	n
1	8.9	0.1	5	n/a	n/a	n/a
2	9.2	0.4	5	8.0	0.4	4
3	9.3	0.3	5	8.5	0.3	4
Average	**9.1**			**8.0**		
Std. Dev	**0.3**			**0.4**		
4	9.0	0.1	5	8.4	0.5	5
5.2	9.0	0.7	3	8.5	0.9	3
6	8.8	0.4	4	7.8	0.6	3
Average	**9.0**			**8.2**		
Std. Dev.	**0.3**			**0.6**		

Table 3.3: Average $\delta^{15}N$of male mummichog muscle and liver tissue across the marsh at each site from the summer sampling.

liver results may simply reflect an increased proportion of fats in liver relative to muscle tissue (Peterson & Fry, 1987). The liver tissues must be solvent extracted before they can be compared to muscle proteins and are not discussed further in this thesis.

3.1.2 Size and Weight Differences

Male mummichog masses were not significantly different at the natural versus ditchplug pools (p=0.167) (Figure 3.3) (Table 3.4). Site 5.2 was the only pool with fish at the fall sampling. This site showed drastic shifts in weight between the summer and fall sampling with a shift from a weight of 2.37±1.4g for the summer sampling to 8.93±2.1g for the fall (Table 3.5) (Figure 3.3).

A two-tailed t-test showed no statistical significance between the lengths of the fish at the natural pools and the ditchplug pools (p=0.099) (Table 3.5). There was an important shift between the summer and fall sampling for site 5.2. Similar with the weight data, the fall sampling of the female mummichog in site 5.2 was found to have the longest fish out of all the data collected (8.68±0.5cm) (Table 3.5) (Figure 3.4).

3.1.3 Gut Contents

The unidentified vegetation content from all sites was about 60% and the animal content was about 40% (Table 3.4). There was no statistically significant difference in the vegetation content among the mummichogs across the marsh (p=0.582) (Table 3.6). A two-tailed t-test showed no significant difference in animal content in the gut of the mummichogs from all the sites (p=0.324) (Table 3.6). Although no statistical signifcance was found from all the sites in vegetation and animal content (p=0.070), there is an observationally distinct difference in vegetation versus animal content in the gut content analyses (Table 3.6).

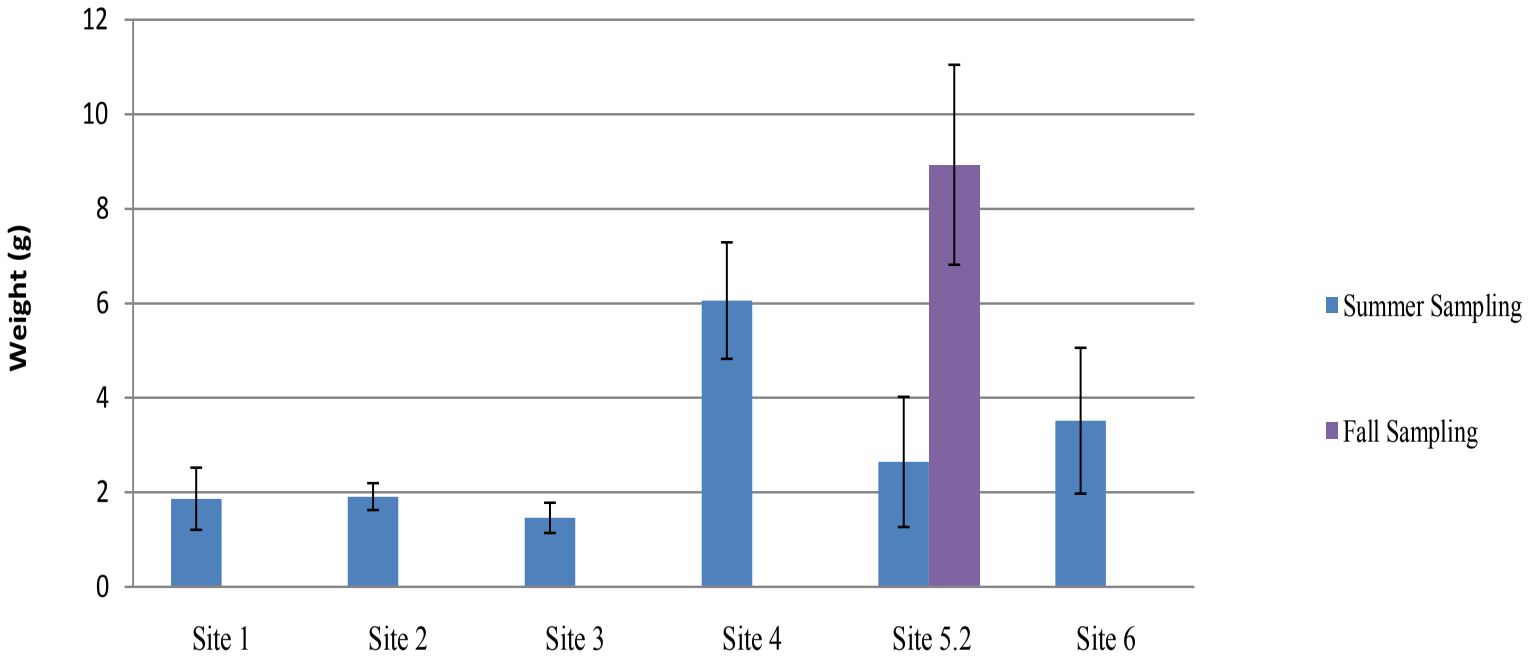

Figure 3.3: Average weight of the male mummichogs collected in the summer sampling (n=5 at each site) and the average weight of the mummichogs collected in the fall sampling (n=5; female). Error bars represent the standard deviation of the average weight of the fish at each site. Sites 1-3= natural pools. Sites 4-6= ditchplug pools.

Site	1		2		3		4		5.2		6	
	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.	Avg.	Stdev.
Features												
Length (cm)	5.1	0.4	5.4	0.2	5.0	0.3	7.3	0.7	5.8	1.0	6.5	0.8
Weight (g)	1.6	0.4	1.9	0.3	1.5	0.3	6.1	1.2	2.4	1.4	3.5	1.5
Gut Contents												
Vegetation (%)	52.3	19.6	92.1	11.4	52.8	21.0	72.8	7.9	61.8	30.0	28.4	20.5
Animal (%)	49.6	22.0	25.0	-	60.4	31.5	28.9	7.8	38.3	19.9	24.4	14.0

Table 3.4: Length, weight, and gut contents analysis of all male mummichogs collected in the summer sampling season. Gut contents were simplified to vegetation and animal content for the purpose of this study. Full gut content analysis can be seen in Appendix B.

Comparison	Average (SE Mean)	n	T-Value	p-value	DF
Weight Data (g)					
N v. DP	N=1.65(0.13) DP=3.98 (1.1)	3; 3	-2.13	0.167	2
Length Data (cm)					
N v. DP	N= 5.13(0.12) DP=6.53 (0.46)	3; 3	-2.94	0.099	2

Table 3.5: Results of two-tailed t-test for size and weight data. N=Natural pools. DP= ditchplug pools. n is the number of replicates used to determine statistical significance between N; DP. DF is the degrees of freedom; the number of values in the final calculation that are free to vary. The T-value is the difference between the mean and average scores of the N and DP groups. p-value is a number expressing the probability of obtaining a test statistic as extreme as the one actually observed, a p-value of <0.05 was considered significant.

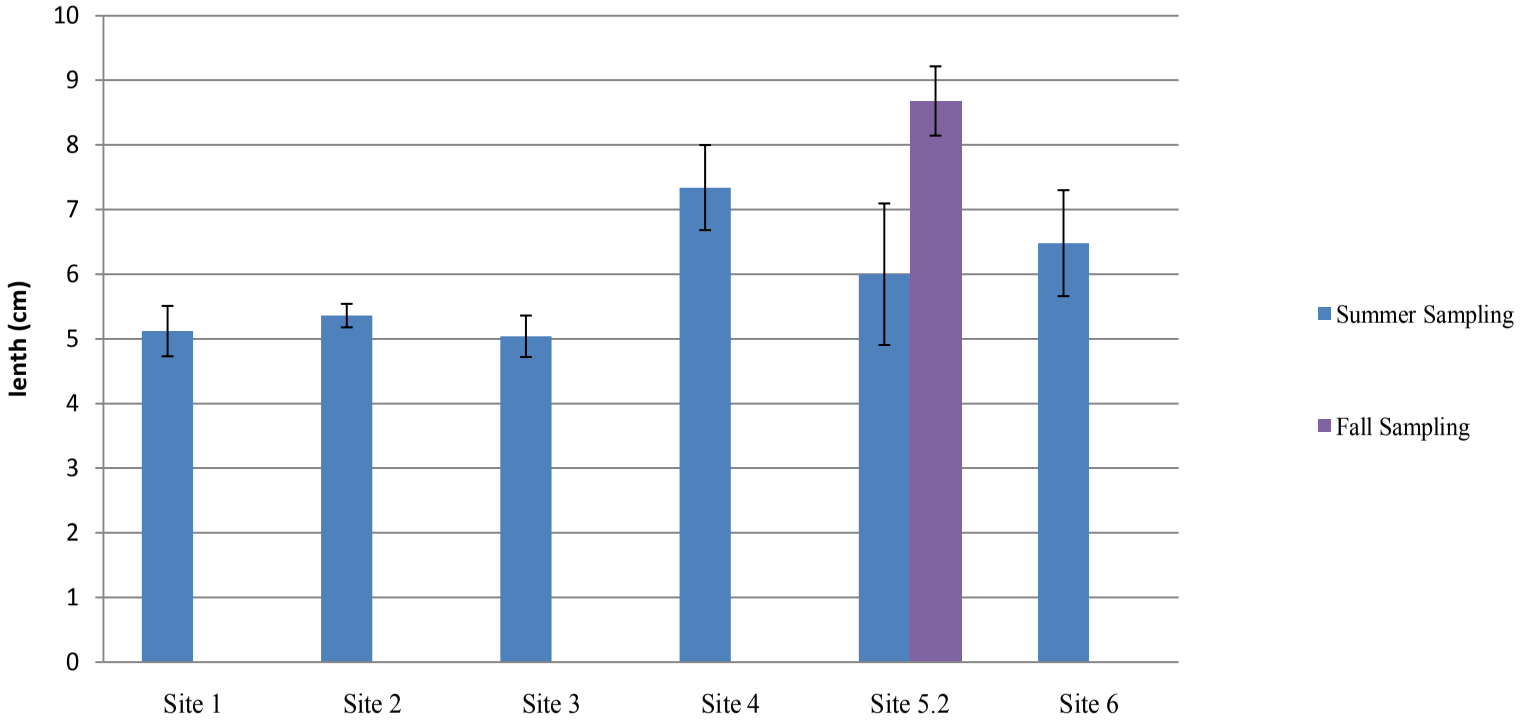

Figure 3.4: Average length of mummichogs collected in the summer sampling of male mummichogs (n=5 at each site) and the fall sampling of mummichogs which are all female (n=5). The error bars represent the standard deviation for the length of the fish at each site. Sites 1-3= natural pools. Sites 4-6= ditchplug pools.

Comparison	Average (SE Mean)	n	T-Value	p-value	DF
Veg Content					
N v. DP	N=55 (13.0) DP=45 (13.0)	3; 3	0.61	0.582	3
Animal Content					
N v. DP	N= 63(10.0) DP=37 (4.0)	3; 3	1.30	0.324	2
Across Marsh					
Veg v. Animal	Veg= 60 (8.8) Animal= 40 (6.0)	6; 6	2.09	0.070	8

Table 3.6: Results of two-tailed t-test for gut content data. N=Natural pools. DP= ditchplug pools. n is the number of replicates used to determine statistical significance between N; DP. DF is the degrees of freedom; the number of values in the final calculation that are free to vary. The T-value is the difference between the mean and average scores of the N and DP groups. p-value is a number expressing the probability of obtaining a test statistic as extreme as the one actually observed, a p-value of <0.05 was considered significant.

3.2 Mummichogs, Surface sediments, POM, and other organisms

3.2.1 Natural Pools

The nereis worm and snail were enriched in $\delta^{13}C$ relative to the POM and surface sediment by about 3-8‰ (Table 3.7) (Figure 3.5). The mummichogs showed a signal similar to the nereis and intermediate between the POM and the snail signal (Table 3.7) (Figure 3.5). The POM had a C/N ratio of 5.9 (±0.5), suggestive of a phytoplankton signal. The mummichogs were at the highest trophic level with $\delta^{15}N$ values of 8.9±0.5‰, 9.2±0.4‰, 9.3±0.3‰ for sites 1, 2, and 3, respectively (Table 3.7). Surface sediment was at the lowest trophic level with $\delta^{15}N$ values of 0.1±0.4‰, 2.4±2.9‰, and 0.8±0.0‰ for sites 1, 2, and 3, respectively (Table 3.7).

3.2.2 Ditchplug Pools

The surface sediment had the lowest $\delta^{15}N$ of 0.8±0.2‰, 2.03±0.2‰, and 1.78±0.3‰ for sites 4, 5.2, and 6 respectively (Table 3.8) (Figure 3.6). The mummichogs had the highest $\delta^{15}N$ values of 9.0±0.1‰, 9.0±0.7‰, and 8.8±0.4‰ for sites 4, 5.2, and 6, respectively (Table 3.8) (Figure 3.6). The POM had a C/N ratio of 7.7 (±0.5), like the natural pools suggestive of a phytoplankton signal. The ditchplug POM $\delta^{15}N$ values were about 5‰ enriched relative to the natural pools and were similar to the $\delta^{15}N$ values of the mumichogs. However, this difference was no statistically signficant ($p=0.250$) (Table 3.9). The enriched POM in the ditchplug sites suggested enrichment in ^{15}N in the nutrients from the ditchplug sites. This showed a fundamentally different biogeochemical cycling in the ditchplug and natural pools.

3.3 Cross-Sectional Elevation

According to the 2007 LiDAR data for Phippsburg, ME there was a 2.2 m difference in elevation across the marsh from the lowest to highest point, taking into consideration the water features on the marsh such as the river and transition into the

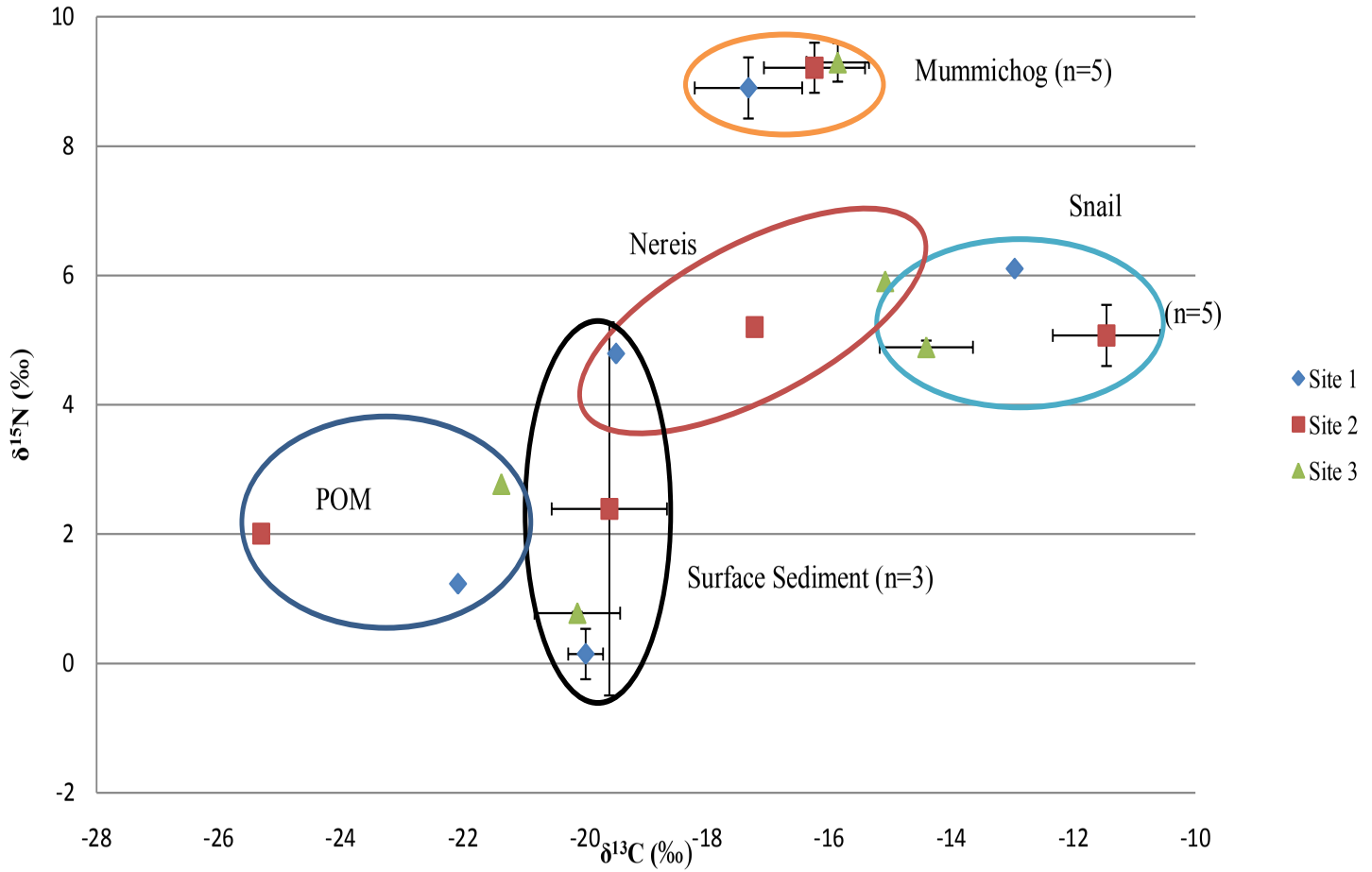

Figure 3.5: Dual isotope plot for the natural pools. The circles indicate the grouping of the components. The orange circle encompasses all of the mummichog data. The turquoise circle marks the snail data. The red circle indicates the nereis data. The black circle encompasses the surface sediment data. The blue circle shows the POM data.

	Average $\delta^{13}C$ (‰)	Stdev (‰)	Average $\delta^{15}N$ (‰)	Stdev (‰)	n
Site 1					
Mummichog (muscle)	-17.3	0.9	8.9	0.5	5
Snail (muscle)	-13.0	-	6.1	-	1
Surface Sediment	-20.0	0.3	0.1	0.4	3
Nereis	-19.5	-	4.8	-	1
POM	-22.1	-	1.2	-	1
Site 2					
Mummichog (muscle)	-16.2	0.8	9.2	0.4	5
Snail (muscle)	-11.4	0.9	5.1	0.5	5
Surface Sediment	-19.6	0.9	2.4	2.9	3
Nereis	-17.2	-	5.2	-	1
POM	-25.3	-	2.0	-	1
Site 3					
Mummichog (muscle)	-15.9	0.5	9.3	0.3	5
Snail (muscle)	-14.4	0.8	4.9	0.1	4
Surface Sediment	-20.1	0.7	0.8	0.0	3
Nereis	-15.1	-	5.9	-	1
POM	-21.4	-	2.8	-	1

Table 3.7: Average $\delta^{13}C$ and average $\delta^{15}N$ of components within the natural pool food web.

	Average $\delta^{13}C$ (‰)	Stdev (‰)	Average $\delta^{15}N$ (‰)	Stdev (‰)	n
Site 4					
Mummichog (muscle)	-18.5	0.7	9.0	0.1	5
Surface Sediment	-20.1	0.7	0.8	0.2	3
POM	-18.2	-	1.3	-	1
Site 5.2					
Mummichog (muscle)	-18.8	0.8	9.0	0.7	5
Surface Sediment	-20.8	2.2	2.0	0.2	3
POM	-21.4	-	7.2	-	1
Site 6					
Mummichog (muscle)	-18.7	0.4	8.8	0.4	5
Surface Sediment	-18.9	1.4	1.8	0.3	3
POM	-21.1	-	7.4	-	1

Table 3.8: Average $\delta^{13}C$ and average $\delta^{15}N$ of components within the ditchplug pool food web.

Comparison	Average (±SE Mean)	n	T-Value	p-value	DF
$\delta^{13}C$ (‰)					
N v. DP	N=-22.9 (1.2) DP=-21.2 (1.0)	3; 3	-1.69	0.189	3
$\delta^{15}N$ (‰)					
N v. DP	N= 2.0(0.4) DP=5.32 (2.0)	3; 3	-1.60	0.250	2

Table 3.19: Stable carbon and stable nitrogen isotopic data for POM in the natural and ditchplug sites. DF is the degrees of freedom; the number of values in the final calculation that are free to vary. The T-value is the difference between the mean and average scores of the N and DP groups. p-value is a number expressing the probability of obtaining a test statistic as extreme as the one actually observed, a p-value of <0.05 was considered significant.

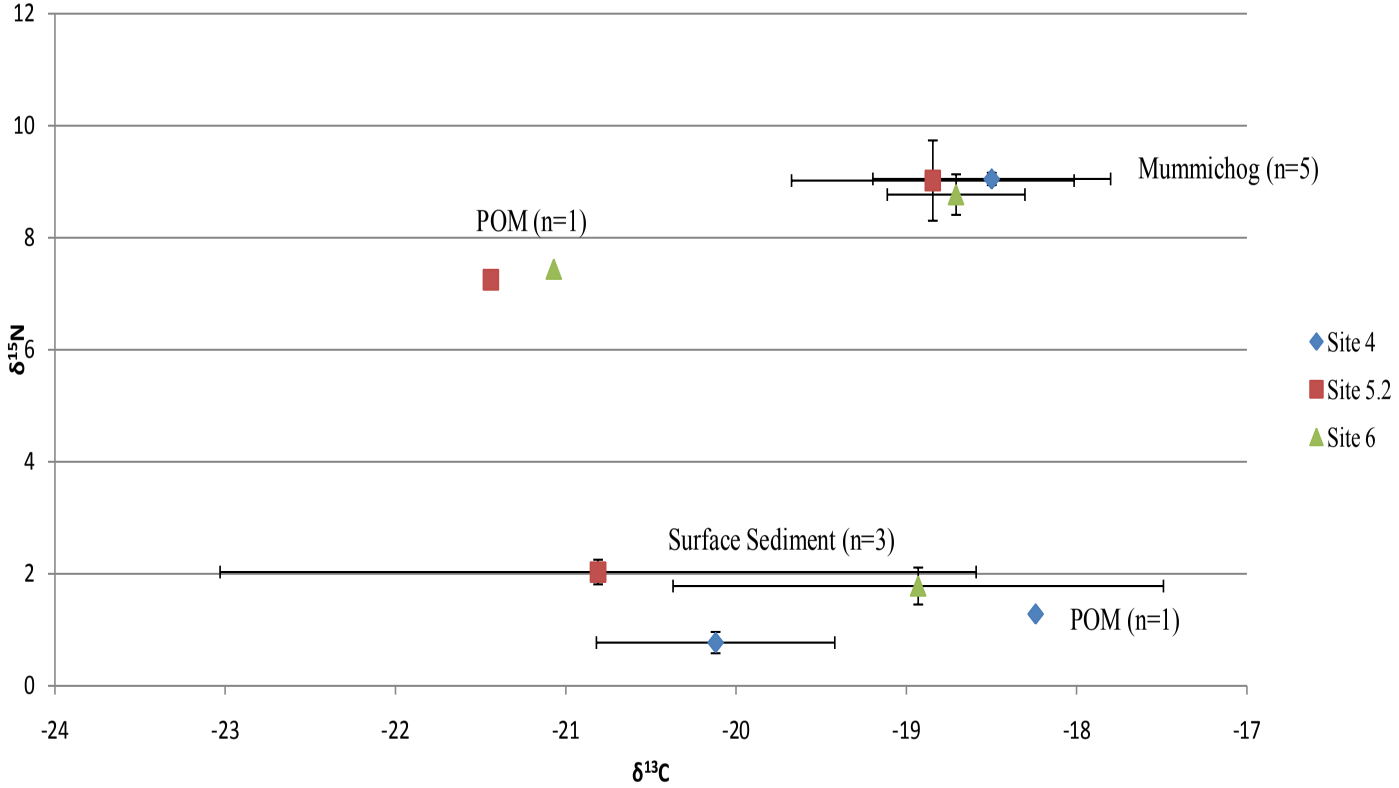

Figure 3.6: Ditchplug pool food web from all sites. Note that the POM from site 4 is enriched relative to the other sites. The error bars a representative of standard deviation. The POM only had an n of 1 so there is no standard deviation for those data.

uplands (JALBTCX, 2011). When just observing the marsh surface without considering tidal creeks, rivers, terrestrial uplands, or ditches the highest elevation was about 1.5 m and the lowest was about 1.3 m (A to A') (Figure 3.7 and Figure 3.8).

3.4 Vegetation

3.4.1 Natural Pool Vegetation

In the natural pool area, there were two main vegetation types (*Spartina patens* (C4) and the short and tall form of *Spartina alterniflora* (C4)) (Figure 3.9). This was very typical for high marsh area such as the one used for the natural study area. Patches of *Juncus gerardii* (C3 plant) were also found around the Southern border of the marsh and on the edge of site 1 (Figure 3.9).

3.4.2 Ditchplug Pool Vegetation

In the ditchplug area, the main vegetation type was *Spartina patens* (C4), typically mixed with *Juncus gerardii* (C3) (Figure 3.10). In a large area of the marsh by site 4, there was a panne with many forbs growing (i.e. *Salicornia europia*, *Limonium nashii*, and *Atriplex patula*) all of which are C3. Another dominant species found was the short form of *Spartina alterniflora* (C4), this was typically found mixed in with *Spartina patens* in the marsh area between the pools. *Ruppia maritima* (C3) was also found in sites 4 and 6. This area of the marsh was bordered with dominantly *Schoenoplectus robustus* (C3), *Juncus gerardii* (C3), and a large area of cat tails (*Typha latifolia*(C3)) (Figure 3.10).

3.5 Water Data

3.5.1 Hydrolab

The hydrolab data collected from the summer sampling was taken two days after a spring tide. Though no statistically significant differences were found between

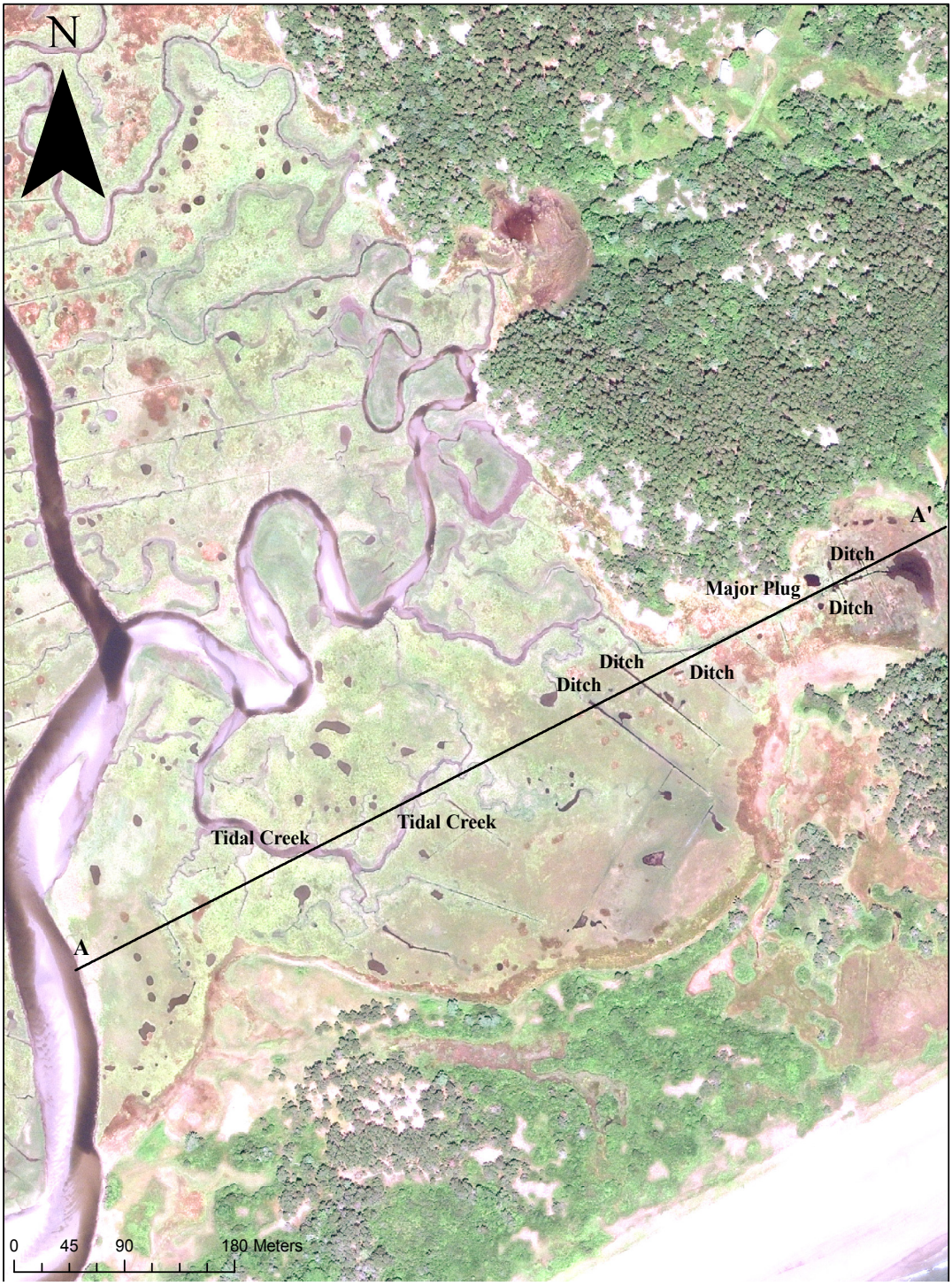

Figure 3.7: Transect A to A' superimposed on a Quickbird satellite image (July 31, 2010). The marsh surface is labeled with ditches and tidal creeks along the transect to shows areas of depression within the extracted LIDAR data. Typical vegetation seen in the high marsh areas were short form *Spartina alterniflora* and *Spartina patens* along with some more rare forbs (i.e. *Atriplex patua* and *Salicornia europaea*). Typical vegetation seen in the higher high marsh was *Spartina alterniflora*, *Spartina patens*, *Juncus geradii*, *Typha latifolia* (cat tails), and *Schoenplectus robustus*.

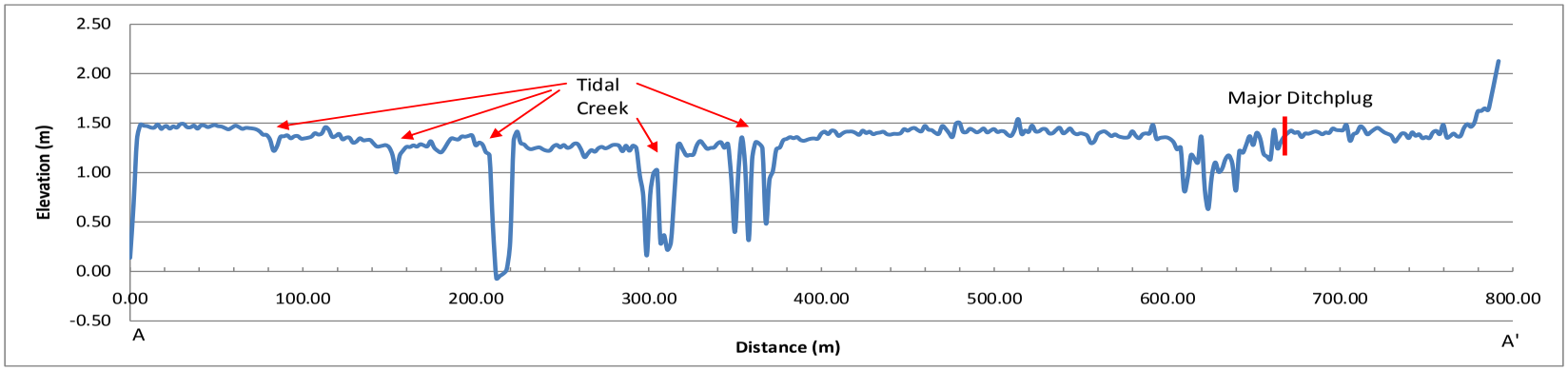

Figure 3.8: Cross section of marsh vegetation from A to A' (See Figure 3.7). The low points represent the surficial low in that particular area.

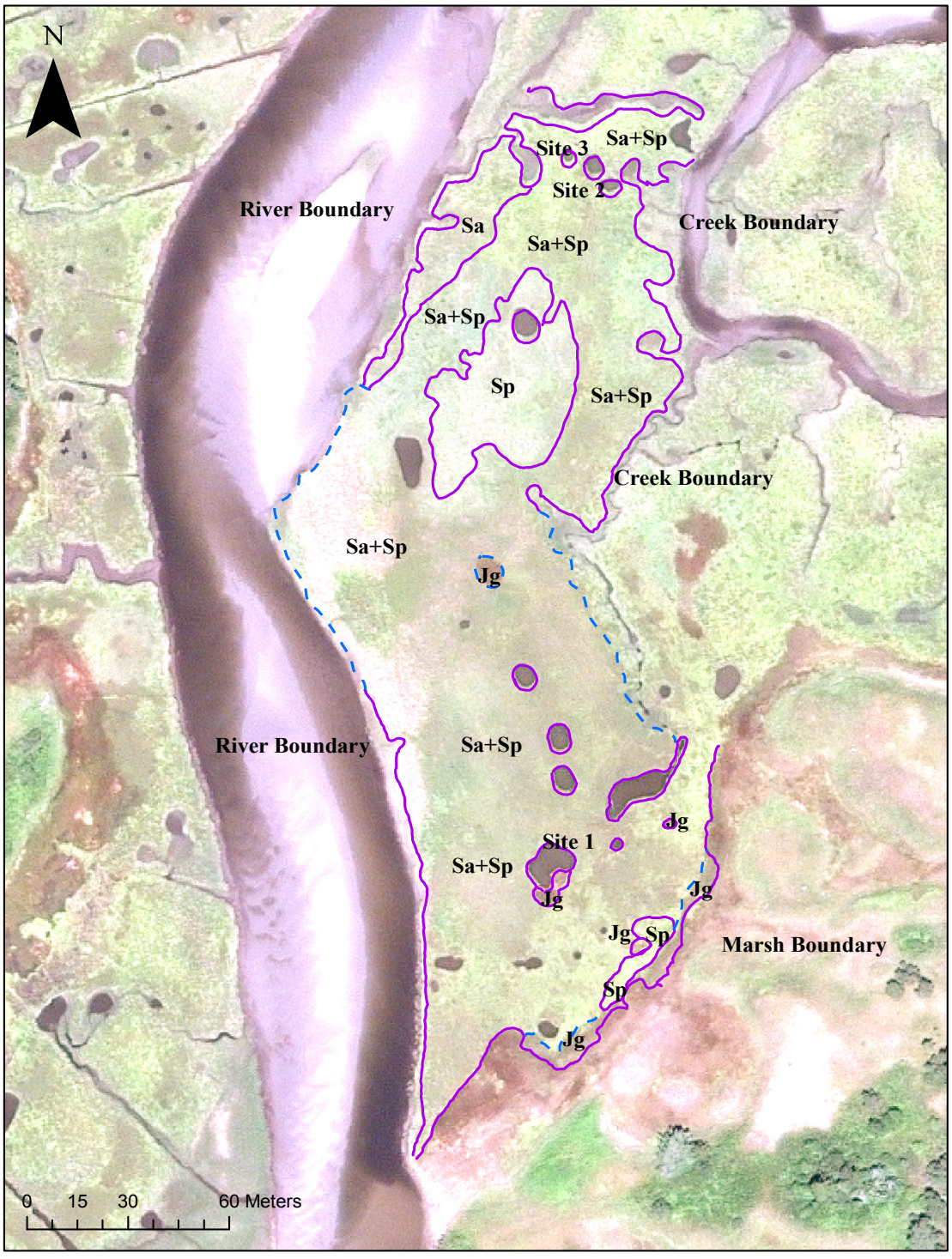

Figure 3.9: Map of the vegetation found at the natural pool sites. The purple lines are the lines walked with the Trimble GPS unit. The blue dashed lines are the inferred boundaries. Sa+Sp= Mix of *Spartina patens* and *Spartina alterniflora*. Sa= Pure *Spartina alterniflora*. Sp=Pure *Spartina patens*. Jg= *Juncus gerardii*.

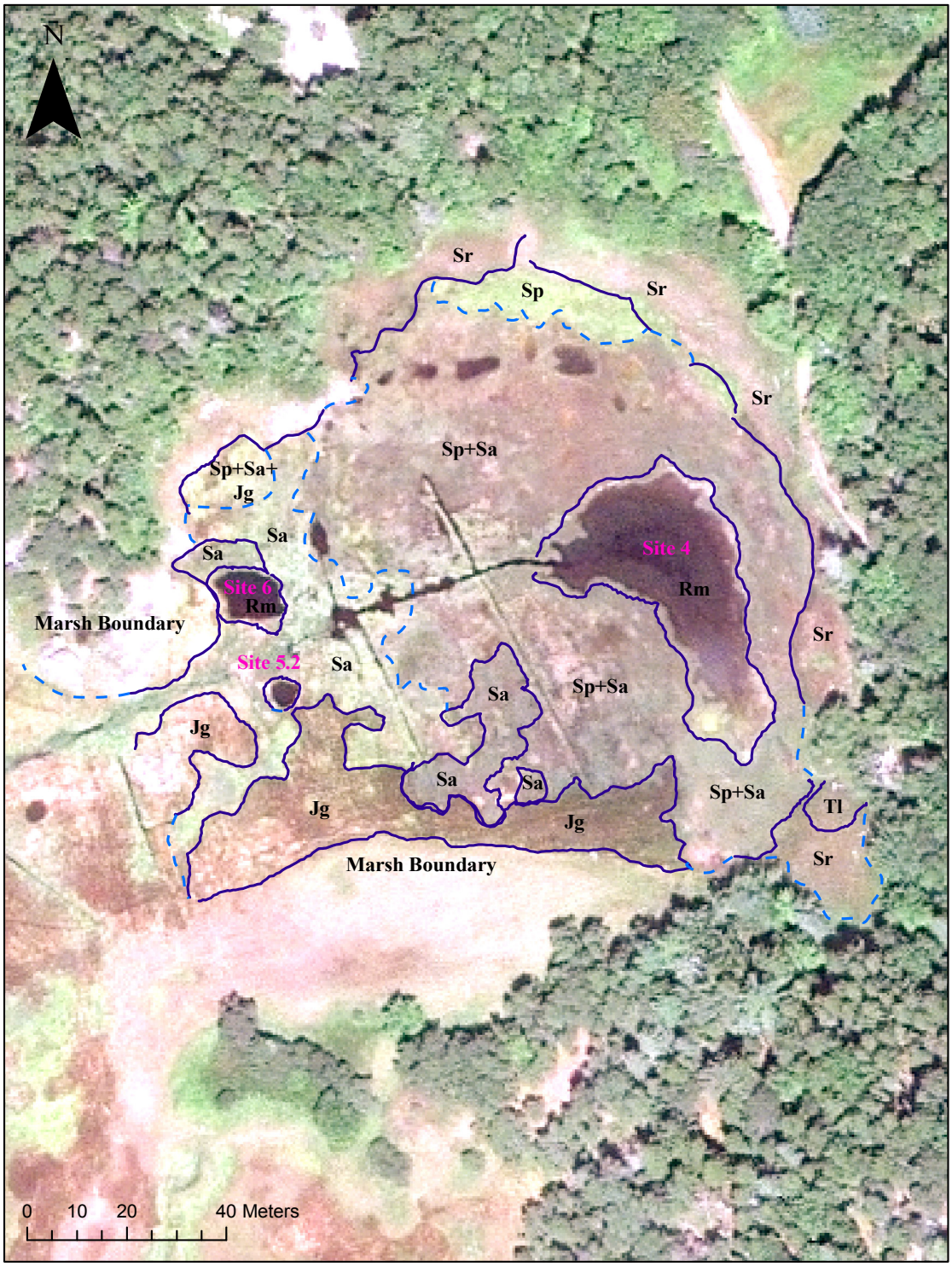

Figure 3.10 Map of the ditchplug pool system. The navy blue lines show the Trimble GPS data recorded in the summer sampling season. The blue dotted lines are inferred boundaries. Sp+Sa+Jg= mix of *Spartina alterniflora*, *Spartina patens*, and *Juncus gerardii*. Sp= pure *Spartina patens*. Sr=*Schoenoplectus robustus*. Tl=*Typha latifolia*. Sp+Sa= Mix of *Spartina patens* and *Spartina alterniflora*. Jg= pure *Juncus gerardii*. Sa= pure *Spartina alterniflora*. Rm= *Ruppia maritima*

the water quality data for the natural and ditchplug pools, SpC and DO appeared to be consistently higher at the natural pools relative to the ditchplug pools (Table 3.10). The average water temperature for the natural pools and ditchplug pools were 15.83±0.45ºC and 18.02±1.9ºC respectively (Table 3.10). The average SpC data for the natural pools was 43.00±0.3 mS/cm and 30.47±9.3 mS/cm for the ditchplug pools (Table 3.10). The average DO for the natural pools was 8.36±1.9 mg/L and 5.18±0.1 mg/L for the ditchplug pools (Table 3.10). The average pH for the natural pools was 7.19±0.2 and 7.01±0.4 for the ditchplug pools (Table 3.10).

The hydrolab data collected during the fall sampling was taken a week after a spring tide. Two-tailed t-tests showed a significant difference only in the SpC and pH data between the natural and ditchplug sites. The average temperature of the water in the natural pools was 6.97 ±0.1ºC and 7.48 ±0.4ºC for the ditchplug pools (Table 3.11). The average SpC for the natural pools was 40.73 ±2.5 mS/cm and 11.64 ±3.0 mS/cm for the ditchplug pools (Table 3.11). The average DO for the natural pools was 15.30±2.0 mg/L and 15.09±0.8 mg/L for the ditchplug pools (Table 3.11). The average pH data for the natural pools was 7.28 ±0.0 and 6.82 ±0.0 for the ditchplug pool (Table 3.11).

3.5.2 Nutrient Data

For the fall sampling the nutrient data was highly variable across the marsh (Table 3.12). For NO_3 data within the natural pools, the data ranged between 14.41 uM and 47.90 uM. The ditchplug pools had slightly less variability with a range of 20.31 uM and 12.33 uM for NO_3 (Table 3.12). The high for $Si(OH)_4$ within the natural pool was 14.01uM and a low of 0.03 uM was detected (Table 3.12). For the ditchplug pools the values ranged from 0.27 uM and 8.87 uM. NH_4 ranged from 0.98 uM to 2.02 uM for the natural pools and from 1.32 uM to 2.38 uM within the ditchplug pools (Table 3.12). The PO_4 data showed a range of 0.5 uM to 0.9 uM for the natural pools and a range of 0.05 uM to 0.30 uM for the ditchplug pools (Table 3.12). The average for the ditchplug pool (0.15 uM) was double that of the natural pools (0.07 uM) for PO_4 (Table 3.12). Due to the

Pool Type	Parameter	Average	Stdev	T-Value	p-value	DF
Natural	Temp (ºC)	15.83	0.4	-1.92	0.195	2
Ditchplug	Temp (ºC)	18.02	1.9			
Natural	SpC (mS/cm)	43.00	0.3	2.33	0.145	2
Ditchplug	SpC (mS/cm)	30.47	9.3			
Natural	DO (mg/L)	8.36	1.9	2.86	0.103	2
Ditchplug	DO (mg/L)	5.18	0.1			
Natural	pH	7.19	0.2	0.71	0.550	2
Ditchplug	pH	7.01	0.4			

Table 3.10: Hydrolab data from the summer sampling (June 28th-30th). The results of the t-tests are placed in the natural pool row, yet are representative of a comparison between the two pool types. DF is the degrees of freedom; the number of values in the final calculation that are free to vary. The T-value is the difference between the mean and average scores of the N and DP groups. p-value is a number expressing the probability of obtaining a test statistic as extreme as the one actually observed, a p-value of <0.05 was considered significant.

Pool Type	Parameter	Average	Stdev	T-Value	p-value	DF
Natural	Temp (ºC)	6.97	0.1	-1.96	0.189	2
Ditchplug	Temp (ºC)	7.48	0.4			
Natural	SpC (mS/cm)	40.73	2.5	13.08	0.001	3
Ditchplug	SpC (mS/cm)	11.64	3.0			
Natural	DO (mg/L)	15.30	2.0	0.17	0.880	2
Ditchplug	DO (mg/L)	15.09	0.8			
Natural	pH	7.28	0.0	5.34	0.033	2
Ditchplug	pH	6.82	0.1			

Table 3.11: Hydrolab data from the fall sampling on October 30, 2010. A two-tailed T-test was performed in order to find significance between the natural and ditchplug pools of each parameter. The results of this test are placed in the natural pool row, yet are representative of a comparison between the two pool types. DF is the degrees of freedom; the number of values in the final calculation that are free to vary. The T-value is the difference between the mean and average scores of the N and DP groups. p-value is a number expressing the probability of obtaining a test statistic as extreme as the one actually observed, a p-value of <0.05 was considered significant.

Pool and Site	$NO_3 + NO_2$ (uM)	$Si(OH)_4$ (uM)	NH_4 (uM)	PO_4 (uM)
Natural Pools				
Site 1	45.96	0.03	1.79	0.05
Site 2	14.51	12.17	2.02	0.09
Site 3	47.90	14.01	0.98	0.08
Average (±stdev)	36.12 (18.7)	8.74 (7.6)	1.60 (0.5)	0.07 (0.0)
Ditchplug Pools				
Site 4	14.53	0.93	1.74	0.30
Site 5.2	12.33	8.87	1.32	0.05
Site 6	34.06	0.27	2.38	0.11
Average (±stdev)	20.31(12.0)	3.36 (4.8)	1.81(0.5)	0.15(0.1)

Table 3.12: Nutrient data from summer and fall testing. Since the data were so variable no statistical analyses were performed.

high variability of the data and lack of replication, no statistics were run.

3.5.3 Sulfate Data

In the summer, two-tailed t-test showed a statistically significant difference between the natural and ditchplug pools in SO_4^{2-} concentrations (p=0.035) (Table 3.13). The average sulfate concentration for the natural pools was 2372±184 mg/L and 1372±283 mg/L for the fall sampling (Table 3.13).

In fall, two-tailed t-test showed a statistically significant difference between the natural and ditchplug pools in SO_4^{2-} concentrations (p=0.001) (Table 3.13). The average sulfate concentration for the natural pools was 2167±185 mg/L and 539±108 mg/L for the ditchplug pools (Table 3.13).

3.5.4 Chlorophyll-a Data

Within the natural pool system the summer data showed chlorophyll-a concentrations that ranged from 1.05 ug/L to 4.51 ug/L and 2.24 ug/L to 8.38 ug/L for the ditchplug pools (Table 3.14). Two-tailed t-test showed no statistical difference between the two areas (p=0.307) (Table 3.15). During the fall sampling the chlorophyll-a data ranged from 1.16 ug/L to 2.45 ug/L in the natural pools and 1.99 ug/L to 2.12 ug/L within the ditchplug pools (Table 3.14). A two-tailed t-test revealed no statistical significance was found between the natural and artificial pools (p=0.406) (Table 3.15).

Two-tailed t-tests were also done to observe any sort of statistically signficant seasonal shift in chlorophyll-a within the two systems. For both the natural and ditchplug pools no shift was found in the chlorophyll-a data between the summer and fall months (p=0.392) (Table 3.15).

3.6 Grain Size

The cores from the ditchplug pools (Site 4-6) were fairly similar (Appendix C). The three cores all had fine roots most likely of *Spartina patens* or *Ruppia maritima*.

Season	Pool Type	Average (mg/L)	SE Mean	T-Value	p-value	DF
Summer	Natural	2372	68	5.17	0.035	2
	Ditchplug	1372	181			
Fall	Natural	2167	92	14.23	0.001	3
	Ditchplug	539	68			

Table 3.13: Data for the average sulfate data from both the fall and summer sampling from the natural and ditchplug pools. There was an n of 3 for both the natural and ditchplug pools. A two-tailed t-test was run on the data as displayed in the natural pool type row of the table.

Site	Summer Chlorophyll (ug/L)	Stdev	n	Fall Chlorophyll (ug/L)	Stdev	n
1	1.05	0.8	3	1.16	0.1	3
2	4.51	0.4	3	2.05	0.1	3
3	3.71	0.9	3	2.45	0.3	3
4	6.34	4.7	3	2.96	1.0	3
5.2	8.38	4.3	3	1.99	0.3	3
6	2.24	0.2	3	2.12	1.8	3

Table 3.14: Average cholorphyll-a data from the natural and ditchplug sites from both sampling seasons.

Comparison	Average (±stdev)	n	T-Value	p-value	DF
Summer Data					
N v. DP	N= 3.09(1.8) DP=5.65 (3.1)	3	-1.23	0.307	3
Fall Data					
N v. DP	N=1.885 (0.7) DP=2.356 (0.5)	3	-0.96	0.406	3
Natural Pools					
Fall v. Summer	Fall= 1.885 (0.7) Summer= 3.09 (1.8)	3	-1.08	0.392	2
Ditchplug Pools					
Fall v. Summer	Fall =2.356 (0.5) Summer = 5.65 (3.1)	3	-1.80	0.214	2

Table 3.15: Shows all results of two-tailed t-tests for chlorophyll-a data from the summer and the fall sampling and for natural (N) and ditchplug (DP) pools. n is the number of replicates used to determine the statistical significance for both groups. DF is the degrees of freedom; the number of values in the final calculation that are free to vary. The T-value is the difference between the mean and average scores of the N and DP groups. p-value is a number expressing the probability of obtaining a test statistic as extreme as the one actually observed, a p-value of <0.05 was considered significant.

They were highly organic and had colors ranging from black to very dark grayish brown (Appendix C). The cores from the natural pools (Sites 1-3) were also fairly similar to each other. Like the ditchplug pools they were highly organic, yet contained more roots. Many of the roots were those of Spartina patens and Spartina alterniflora. The natural pool cores also contained much more sand than found in the ditchplug sites (Appedix C).

No statistical significance was found in grain size between the natural and ditchplug sites ($p=0.203$) (Table 3.16). Although no statistically significant difference was found, it appears as though the natural pools had nearly triple the amount of sand as the ditchplug pools. The average weight of the sand was 0.12 ± 0.08g and 0.03 ± 0.01g in the natural and ditchplug sites, respectively (Table 3.16).

Site	Average (%Sand)	SE Mean	T-value	p-value	DF	n
N v. DP	N= 2.07 DP= 1.87	0.55 0.24	0.33	0.772	2	3;3

Table 3.16: Grain size analysis results for the % sand of the sediment after all of the organics were burned off.

Discussion

4.1Elevation

Figure 4.1 shows a cross section of LiDAR data from the Sprague River to the edge of the marsh in the natural pool system. Low marsh vegetation is found within 8 meters of the river and over elevations of 0.7 to 1.5 meters above sea level rise. The vegetation found in this area of the marsh is the tall and short form of *Spartina alterniflora*. The low marsh transitions into high marsh at approximately 20 meters from the river and transitions into the higher high marsh and dunes at around 100 meters. The elevation across the high marsh is about 1.5 meters and varies by only 13 cm. All three natural pool sites are found in the high marsh. The vegetation in this area is a mix of the short form *Spartina alterniflora* and *Spartina patens* both of which are C4 vegetation. The transition from the high marsh to the higher high marsh and uplands marks a shift to terrestrial C3 vegetation of dune grasses.

Figure 4.2 shows two different cross sections of marsh elevation in the ditchplug study area. The A to A' transect shows the morphology from the central ditch to the marsh boundary. The LiDAR data show no indication of a low marsh section in this transect. This correlates with the vegetation mapped while in the field; suggestive of a relationship between elevation and plant species growth. The morphology of this transect shows a transition from high marsh at 55 meters from the ditch to the terrestrial uplands. The lowest elevation of this surface is approximately 1.4 meters above sea level rise and varies about 12 cm. At 50 meters there is a shift to higher elevation that is dominated by the C3 plant *Juncus gerardii*. From this point the elevation increases significantly into the uplands.

The B to B' transect shows the marsh from site 4 to the edge of the marsh (Figure 4.2). The transect has a low of 1.4 meters transitioning into the uplands approximately 2 meters from the edge of the pool (Figure 4.2). At about 15 meters across the transect, observations were made about the marsh surface which suggested waterlogging and sinking of the peat. At this point the elevation is 1.5 meters. Although this is a low

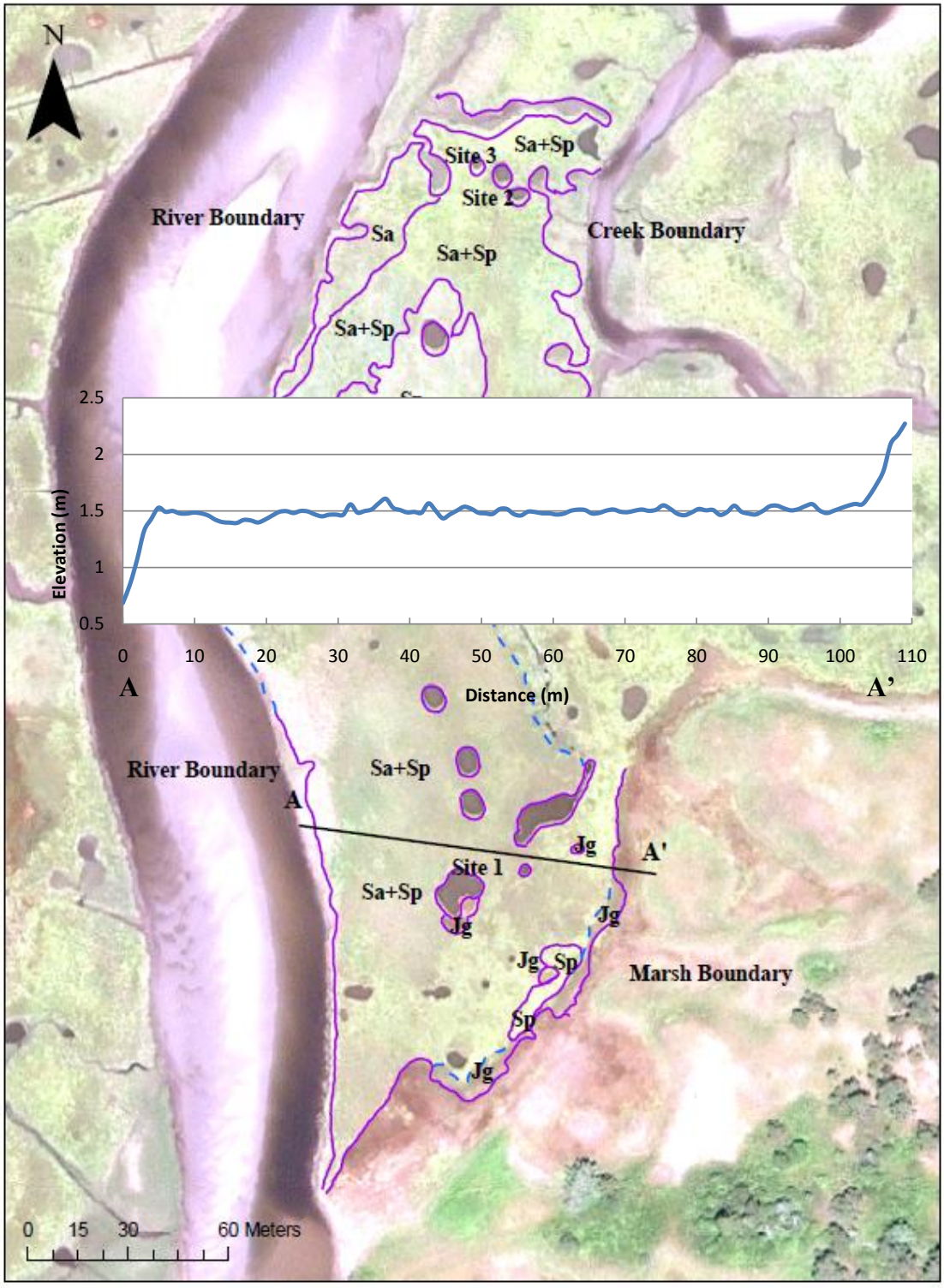

Figure 4.1: Extractions of 2007 LIDAR data superimposed on a Quickbird satellite image (July 31, 2010). The Transect is from A to A' and the elevation shifts are seen in the graph above. The purple lines are the lines walked with the Trimble GPS unit. The blue dashed lines are the inferred boundaries. Sa+Sp= Mix of *Spartina patens* and *Spartina alterniflora*. Sa= Pure *Spartina alterniflora*. Sp=Pure *Spartina patens*. Jg= *Juncus gerardii*.

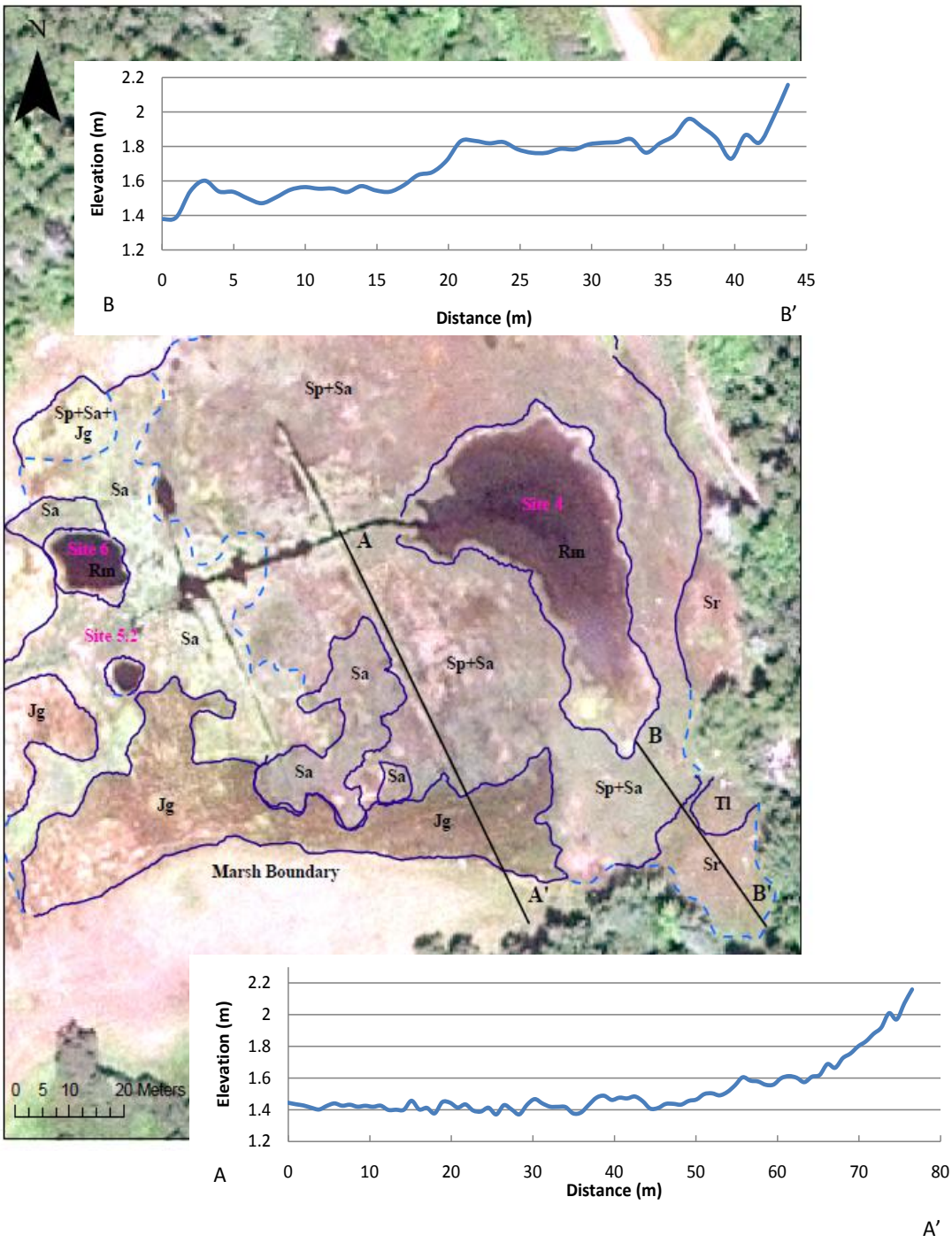

Figure 4.2: Extraction of 2007 LIDAR superimposed on a Quickbird satellite image (July 31, 2010). Two transects A to A' and B to B' show two different parts of the ditchplug area that have noteworthy shifts in elevation. The navy blue lines show the Trimble GPS data recorded in the summer sampling season. The blue dotted lines are inferred boundaries. Sp+Sa+Jg= mix of *Spartina alterniflora*, *Spartina patens*, and *Juncus gerardii*. Sp= pure *Spartina patens*. Sr=*Schoenoplectus robustus*. Tl=*Typha latifolia*. Sp+Sa= Mix of *Spartina patens* and *Spartina alterniflora*. Jg= pure *Juncus gerardii*. Sa= pure *Spartina alterniflora*. Rm= *Ruppia maritima*

point in elevation in this transect, it is still higher than marsh covered in transect A to A'. This area is of particular importance due to its unique properties such as, vegetation distribution and observations of sinking peat. This area needs to be researched further in order to gain a better understanding of the overall health of Sprague Marsh.

Although the error on the LiDAR data is 20 cm, there appears to be a 10 cm lower high marsh in the ditchplug pools relative to the natural pools. This could be attributed to a lack of sedimentation in this region or excess decomposition rates. A lack of sedimentation could either be from low sediment input from the uplands or from the tidal restriction created by the major plug. Decomposition rates in the ditchplug area of the marsh could be a little bit higher either due to sulfide toxicity or waterlogged sediment creating an anoxic environment to microbial decomposers. A study done by Portnoy (1999) showed that waterlogged peat is anaerobic, thus slowing down decomposition rates compared to oxygenated peat. Although at first could slow down decomposition, waterlogged peat and long periods of anoxia could result in sulfide toxicity. Oxygen converts sulfide into sulfate, but in anoxic sediments sulfide builds up and becomes toxic to plants (Wang & Chapman, 1999). Thus, stimulating decomposition and perhaps lowering the elevation. This could be happening where pannes are forming in the ditchplug area of the marsh, however this needs to be investigated further.

4.2 Vegetation

The vegetation map for the natural pool area (Figure 3.9) is dominated by C4 salt marsh vegetation. The two main types of vegetation seen in this area are *Spartina alterniflora* and *Spartina patens*, both C4 plants (Table 4.1). These are typical low and high marsh cord grasses. The small areas of *Juncus gerardii* by site 1 (Figure 3.9) is the only C3 plant in close proximity to the natural pools.

The vegetation map for the ditchplug pool area (Figure 3.10) is a heterogeneous mix of C3 and C4 vegetation. This area has *Spartina alterniflora*, *Spartina patens*, *Juncus*

Parameter	N (±stdev)	DP (±stdev)	p-value
Summer Data			
δ^{15}N-Muscle	9.1 (0.3)	9.0 (0.3)	0.295
δ^{13}C-Muscle	-16.5 (0.9)	-18.7 (0.5)	0.039
Fish Weight	1.65 (0.2)	3.98 (1.9)	0.167
Fish Length	5.13 (0.2)	6.53 (0.8)	0.099
Pool Biodiversity	MC ,SS,POM, MS, SN, W	MC, SS, POM, W	
δ^{15}N POM	2.0 (0.8)	5.3 (3.5)	0.250
δ^{13}C POM	-22.9 (2.1)	-21.2 (0.3)	0.189
C/N POM	5.9 (0.5)	7.7 (0.5)	
Vegetation Distribution	C4	C3 + C4	
DO-Summer	8.36 (1.9)	5.18 (0.1)	0.103
Temp-Summer	15.83(0.4)	18.02 (1.9)	0.195
pH-Summer	7.19 (0.2)	7.01 (0.4)	0.550
SpC-Summer	43.00 (0.3)	30.47(9.3)	0.145
SO_4^{2-} Summer	2372 (184)	1372 (283)	0.035
Chlorophyll-a Summer	3.09 (1.8)	5.65 (3.1)	0.307
Fall Data			
DO-Fall	15.30 (2.0)	15.09 (0.8)	0.880
Temp-Fall	6.97 (0.1)	7.48 (0.4)	0.189
pH-Fall	7.28 (0.0)	6.82 (0.1)	0.033
SpC-Fall	40.73 (2.5)	11.64 (3.0)	0.001
NO_3^-	36.12 (18.7)	20.31 (12.0)	
$Si(OH)_4$	8.74 (7.6)	3.36 (4.8)	
NH_4^+	1.60 (0.5)	1.81 (0.5)	
PO_4^{2-}	0.07 (0.0)	0.15 (0.1)	
SO_4^{2-} Fall	2167 (185)	539 (108)	0.001
Chlorophyll-a Fall	1.885 (0.7)	2.356 (0.5)	0.406

Table 4.1: All averages of data collected and corresponding two- tailed t-test results for the natural and ditchplug pools. MC= mummichog, SS= surface sediment, POM= particulate organic matter, MS= mussel, SN= snail, W= worm

gerardii, and many C3 sedges and terrestrial plants present.

4.3 Salinity and Hydroperiod

Salt marsh vegetation species (halophytes (Silvestri & Marani, 2004)) are distinctive to salt marsh vegetation and aid in the explanation of carbon cycling within the marsh system (Sousa *et al.*, 2010). The characteristics of the different salt marsh species are driven by salinity and hydroperiod and therefore as discussed earlier, surface elevation. The high density of C4 vegetation in the natural pool area is characterstic to the high saline environment of the natural pool area (Figure 4.1). The low marsh area is primarily the ideal growing conditions for *Spartina alterniflora*, a grass that can live in high saline waters and has a high tolerance for water inundation. The high marsh vegetation also has a high tolerance for saline waters, however due to the shorter hydroperiod the introduction of *Spartina patens* is seen in this area. The SpC data for the natural pools was 40.73 (±2.5) mS/cm and the sulfate concentration was 2372 (±184) (Table 4.1).

The shift towards a mix of C4 and C3 vegetation seen in the ditchplug area is likely due to the lower salinity and the fact that it is a tidally restricted area to some degree (Figure 4.2). The SpC value for the ditchplug pools in the summer was 30.47 (±9.3) mS/cm and a sulfate concentration of 1372 (±283mg/L) (Table 4.1). The low salinity in the ditchplug area relative to the natural pools is probably due to freshwater input from the uplands as well as a reduction in tidal flow from the major plug. The effects of tidal restrictions have a strong effect on the desalination of the marsh, thus affecting the biogeochemical cycling and productivity (Portnoy & Valiela, 1997).This needs to be researched further in order to better understand the relationship between salinity, hydroperiod, and vegetation cover.

4.4 Fish Diets and Isotopic Signature

A combination of stable carbon and nitrogen isotope analysis and gut content

analysis is a useful way to reconstruct the path of carbon through the food web within a salt marsh system (McMahon *et al*., 2005). The gut contents in this study showed 60% unidentified vegetation and 40% animal content. McMahon *et al*. (2005) found higher vegetation content in their gut content analysis; vegetation content averaged about 78% within the mummichog guts. Although less vegetation content was found in comparison to McMahon *et al*. (2005), it still suggests a detritus driven diet. However, gut contents only provide an instantaneous snapshot of the fish diet; the isotope data provides a long term view of the diet.

The $\delta^{13}C$ isotopic signatures in this study for the male mummichog muscle tissue in the natural and ditchplug pools were -16.8‰ (±0.9‰) and -18.6 ‰ (±0.5‰) respectively. Based on the vegetation maps it is evident that the enrichment in the natural pools is driven in part by the vegetation. C4 plants provide an area of fish enriched in ^{13}C, while a mix of C3 and C4 plants result in a depleted signal. This is in agreement with Mackenzie & Dionne (2007), Wozniak *et al.* (2006), and McMahon *et al*. (2005). The natural pool section of the marsh is dominated by C4 vegetation. The ditchplug area of the marsh has a mix of C3 and C4. A close examination of $\delta^{13}C$ of mummichogs reveals more enriched values at sites 2 and 3, which are completely surrounded by C4 plants. Slightly more ^{13}C depleted mummichogs are found in site 1, where *J.gerardii* is found.

No significant difference in $\delta^{15}N$ for mummichog muscle tissue was found across the marsh ($\delta^{15}N$=9‰) (Table 4.1). This shows that the mummichogs occupy the same trophic level across the marsh and are the secondary consumers (as found in Judice (2010) and McMahon *et al*. (2005)).

4.5 Species Present

Although a quantitative analysis of biodiversity in the pools was not performed, the natural pools contained more species relative to the ditchplug pools (Table 4.1). All the natural pools contained mummichogs, snails, worms, and mummichogs (with

the exception of one silverside from site 5.2) were the only organism found within the ditchplug pool system for both this study and Judice (2010). Sites 4 and 5.2 both contained *R. maritima*.

The high number of species found in the natural sites was also found in the study by Judice (2010). Within her natural pool systems she found mummichogs, shrimp, mussels, and snails. This increase in species could be due to the natural pools close proximity to the Sprague River and simply a more appealing environment for multiple species. This difference in species presence needs to be researched further in order to gain a better understanding of how these two different pool types function in terms of biodiversity.

4.6 POM

The POM represents a mixture of the plant detritus, phytoplankton, and mineral material within the water column (McMahon *et al*., 2005). The isotopic composition of the POM represents the mix of sources and the isotopic fractionation that occurs between these sources. The natural pool system measured a $\delta^{15}N$ of 2.0 (±0.8‰), indicating an isotopic signature of primary producers. However, no significant difference was found in $\delta^{15}N$ of the POM between the natural and ditchplug sites ($p=0.250$). The $\delta^{15}N$ of the POM for the ditchplug pools was 5.3(±3.5‰). This enrichment in $\delta^{15}N$ could be attributed to a different source of nitrogen or the large fractionation during denitrification process within that system. Denitrification is the reduction of nitrate within a system to produce N_2 (Sharp, 2007). The denitrification process is most intense in poorly drained or less oxygenated sediments, thus an enriched signal in the ditchplug sites of $\delta^{15}N$ would be expected (Sharp, 2007). This enrichment needs to be investigated further.

The average $\delta^{13}C$ of POM for the natural sites is -22.9 (±2.1‰). The average $\delta^{13}C$ of POM for the ditchplug sites is -21.2 (±0.3‰). The C/N ratios for the natural and ditchplug pools are 5.9 (±0.5) and 7.7 (±0.5), respectively. Both ratios are relatively low

suggestive of a phytoplankton signal.

The enrichment in $\delta^{13}C$ of POM for the ditchplug sites and depletion of POM in natural pools is in contrast to the trends seen in the isotopic composition of the mummichogs. While $\delta^{13}C$ vegetation is positively related to the mummichog $\delta^{13}C$ values, the $\delta^{13}C$ POM is not. The carbon of the POM in the pools must be derived from sources other than decomposing vegetation.

One possible factor that may be influencing the $\delta^{13}C$ POM is the rate of primary production in the water column. When photosynthesis rates are high, there is less fractionation during carbon assimilation, resulting in more enriched isotopic values (Fogel & Cifuentes, 1993). Chlorophyll-a concentrations can be used as a proxy for primary production. Although chlorophyll-a concentrations are not statistically significantly different from the natural pools, general trends of the data show that it is consistently higher in the ditchplug area of the marsh. This could indicate higher rates of primary production and enriched $\delta^{13}C$ than would otherwise occur.

The $\delta^{13}C$ POM values in this study are different from those of Judice (2010). Judice (2010) measured more depleted $\delta^{13}C$ values for POM in ditchplug pools than in natural pools. The $\delta^{13}C$ of fish in this study do not differ from Judice (2010) suggesting fish are stable in their trophic habits (Figure 4.3). POM reflects dynamic biogeochemical cycling of carbon in the water column of these pools.

The $\delta^{13}C$ of POM can be influenced by the source of carbon being assimilated by phytoplankton. There are three different carbon sources that may be taken up by the phytoplankton including, organic acids (breakdown of any organic plant matter), diffusion of CO_2 from the atmosphere into the pools, and HCO_3^- in the water column (Figure 4.4). Organic carbon enters the water column through the fixation of inorganic carbon by *Spartina*, benthic micro-algae, and phytoplankton, which is then released into the water column through respiration (Weigert *et al.*, 1981; Sousa *et al.,* 2010). The carbon is then taken up by other organisms through consumption. How these different

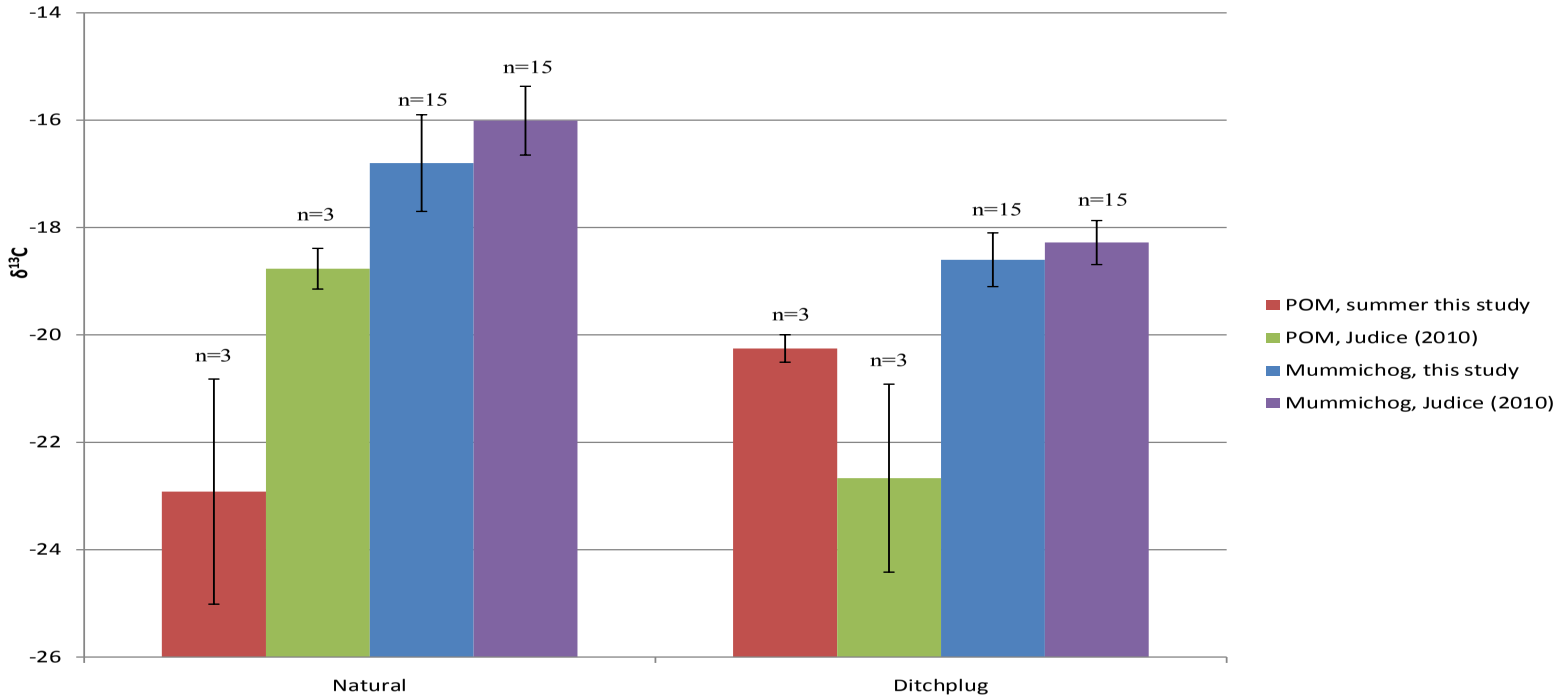

Figure 4.3: Comparison of average $\delta^{13}C$ of POM and mummichogs in the natural and ditchplug sites from this study and Judice (2010). The error bars represent standard deviation.

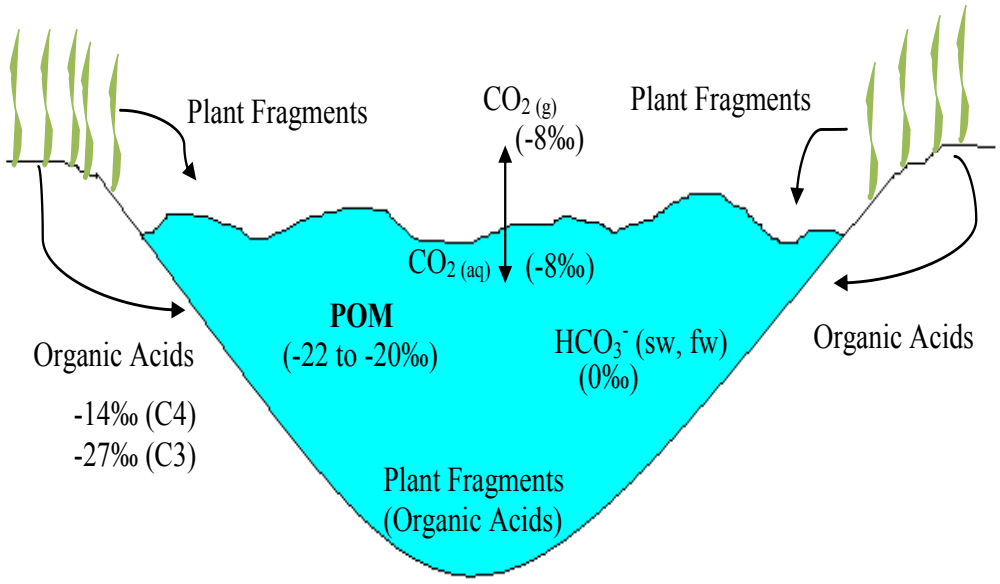

Figure 4.4: Schematic drawing of carbon sources and isotopic composition all of which effect $\delta^{13}C$ of POM in the pool environment. The three sources are organic acids from plant matter which are derived from decomposition of C3/C4 plants, or other organic matter present, CO2 from the atmosphere, and the presence of HCO_3^- from both salt water (sw) and fresh water (fw) sources. The isotopic values for CO_2 and HCO_3^- are derived from table II in Fogel and Cifuentes (1993).

sources are incorporated within the environment can drive variation in $\delta^{13}C$ POM. POM collected by Judice (2010) may have reflected vegetation distributions and influence of carbon derived from organic acids at the two sites. POM collected in the natural pools in this study may reflect organic acids. The POM collected from the ditchplug pools, however, may reflect increased rates of primary production.

In addition to slightly higher chlorophyll-a concentrations in the ditchplug pools (average= 5.65 (±3.1 ug/L) suggesting higher rates of photosynthesis, the temperature in the ditchplug pools was higher than the natural pools in the summer. A higher temperature also increases rates of primary production within a system. Lastly, the lower DO value for the ditchplug area (5.18 (±0.1 mg/L)) in comparison to the natural pools (8.36 (±1.9 mg/L)) (Table 4.1) suggests an increased rate of respiration in the ditchplug sites. This increase in respiration could be from an algal bloom, suggestive of increased primary production. It is likely that the $\delta^{13}C$ POM in ditchplug pools are enriched in ^{13}C relative to the POM in the natural pools due to higher rates of primary production in the ditchplug pools. Thus the $\delta^{13}C$ POM has the potential to provide a shorter term signal of carbon cycling in these pools than found through fish analysis.

Conclusions

One of the goals of this study was to gain a better understanding of how pools function when influenced and not influenced by salt marsh restoration. This study provided a quantitative look at the carbon cycling within the two different pool types in hopes to understand how they function at a chemical level. A quantifiable method was used to gain a better understanding of how pools operate at the biogeochemical level. Through using this method differences between the functioning of the two pool types were found.

The biggest differences seen between the pools were in the $\delta^{13}C$ of mummichog muscle tissue, mummichog size, surface vegetation, grain size, species count, and elevation. The isotopic composition of the mummichogs was likely driven by vegetation shifts across the marsh. The natural pools were fairly homogeneous with C4 coverage, while the ditchplug sites had a more heterogeneous mix of C3 and C4 vegetation. The natural pools were enriched in ^{13}C relative to the ditchplug pools. The $\delta^{15}N$ for the two sites remained constant.

The shifts in vegetation were likely due to differences in salinity and hydroperiod in the two areas. Elevation also played a role in this shift with the natural marsh 0.1 meters higher than the ditchplug area. The differences in these aspects drive the vegetation cover in these two areas, thus influencing the isotopic composition of the mummichogs in the two different pool types.

The POM enrichment in ^{13}C in the ditchplug sites is likely due to increased rates of primary production. This is driven from different sources of carbon in this area. The enriched $\delta^{15}N$ POM in this area is likely due to a different source of nitrogen within the system or representative of isotopic fractionation from denitrification.

5.1 Future Work

Future work should include a similar sampling method in terms of mummichogs, surface sediment, and hydrolab data collection. In order to gain a better understanding

of the species count differences within the pools it would be better to have a more quantitative sampling method in order to compare the ditchplug and natural pools. Further work should also include extensive nutrient studies with the Marine Science Lab at University of Maine at Orno in order to better understand how these two pool types function at a nutrient level. Also, elevation plays a major role in vegetation and overall marsh health. It is important that future work has an extensive survey method in order to track any elevation shifts seen across the marsh.

The hydrological settings of the two sites were distinctly different. However little quantitative data was collected in this area.The natural pools were much closer to the Sprague river channel as the ditchplug pools were much closer to the uplands, perhaps showing an increased freshwater input relative to the natural pools. Future work would be benefited by a stronger look into the hydrological setting of the two study areas.

Lipid extraction should also be done in order to have a comparative isotopic signature of short and long term diets. The lipid extraction would create a protein substance rather than a fatty substance enabling comparison to the muscle tissue. This in conjunction with the gut content analysis and isotope analysis of muscle tissue will provide a longer time scale of diet and potential shifts in diets of mummichogs across the marsh.

Further analysis of the biomass cores could provide information on benthic organism communities in the pools. This could provide further analysis of the transfer of carbon in the two different pools and provide further information on their biogeochemical cycles.

It is imperative to have a detailed analysis of primary production and carbon uptake within the pools. This could be done by a more extensive study on soil and microbial decomposers use of carbon and nitrogen. The potential presence of sulfide toxicity in the ditchplug area of the pool needs to be addressed through a focus on the nutrients available in the sediments.

If one were to only study the ditchplug area, a better study area comparison would be another brackish area of the marsh not influenced by ditchplug restoration (Figure 4.5). This could enable a better understanding of the effects of freshwater input and sedimentation rates.

Figure 4.5: Areas of potential future work. The red circle represents the ditchplug area studied in this study. The blue circle indicates another brackish area of the marsh that is not influenced by ditchplug restoration.

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Appendix A

Analysis	BCID	Mass (mg)	Sample Info	Site	Type	N (umoles)	d15N	C (umoles)	d13C	C/N (Molar)	Date Run	Date Collected	Size (cm)	Sex
854	6586	0.46	F.Heteroclitus	1	muscle	4.57	8.84	17.33	-16.92	3.79	6/22/2010	6/3/2010	5.3	M
855	6587	0.54	F.Heteroclitus	1	muscle	5.34	8.91	20.25	-17.88	3.79	6/22/2010	6/3/2010	5.7	M
856	6588	0.78	F.Heteroclitus	1	muscle	7.72	8.77	30.45	-17.49	3.95	6/22/2010	6/3/2010	5	M
857	6589	0.74	F.Heteroclitus	1	muscle	7.24	8.94	28.17	-16.42	3.89	6/22/2010	6/3/2010	4.9	M
858	6590	0.54	F.Heteroclitus	1	muscle	4.85	9.04	19.22	-17.89	3.96	6/22/2010	6/3/2010	4.7	M
864	6593	0.93	G. aculeatus	1	muscle	9.25	11.71	35.30	-19.46	3.82	6/22/2010	6/3/2010	6.2	M
865	6594	0.81	G. aculeatus	1	muscle	8.29	11.25	30.79	-18.79	3.71	6/22/2010	6/3/2010	6.9	M
866	6595	0.50	G. aculeatus	1	muscle	4.89	11.12	18.77	-18.52	3.84	6/22/2010	6/3/2010	6.4	M
867	6596	0.77	G. aculeatus	1	muscle	6.44	10.01	27.97	-20.27	4.34	6/22/2010	6/3/2010	5.8	M
868	6597	0.59	G. aculeatus	1	muscle	5.42	11.58	21.83	-19.74	4.03	6/22/2010	6/3/2010	5.9	M
859	6591	0.84	Crab	1	muscle	8.08	8.17	30.47	-17.55	3.77	6/22/2010	6/3/2010		
860	6592	0.96	Crab	1	muscle	5.17	6.81	23.44	-16.30	4.54	6/22/2010	6/3/2010		
869	6598	0.84	Snail	1	muscle	6.73	6.10	27.87	-12.96	4.14	6/22/2010	6/3/2010		
2332	6599	0.60	F.Heteroclitus	2	muscle	6.19	9.02	22.98	-15.01	3.71	9/29/2010	6/28/2010	5.1	M
2334	6600	0.89	F.Heteroclitus	2	muscle	9.08	9.20	33.68	-15.85	3.71	9/29/2010	6/28/2010	5.4	M
2336	6601	0.38	F.Heteroclitus	2	muscle	3.71	9.57	14.30	-16.56	3.86	9/29/2010	6/28/2010	5.4	M
2337	6602	0.80	F.Heteroclitus	2	muscle	8.10	9.60	30.67	-17.14	3.79	9/29/2010	6/28/2010	5.6	M
2339	6603	0.43	F.Heteroclitus	2	muscle	4.12	8.68	15.85	-16.64	3.85	9/29/2010	6/28/2010	5.3	M
2333	6599	0.43	F.Heteroclitus	2	liver	3.17	7.65	17.42	-16.81	5.50	9/29/2010	6/28/2010		M
2335	6600	0.36	F.Heteroclitus	2	liver	3.05	8.42	14.22	-17.20	4.67	9/29/2010	6/28/2010		M
2338	6602	0.98	F.Heteroclitus	2	liver	7.13	8.34	38.95	-18.48	5.46	9/29/2010	6/28/2010		M
2340	6603	0.50	F.Heteroclitus	2	liver	3.70	7.78	20.69	-17.43	5.60	9/29/2010	6/28/2010		M
2341	6604	0.65	Snail	2	muscle	5.38	5.40	21.92	-12.39	4.08	9/29/2010	6/28/2010		
2342	6605	0.35	Snail	2	muscle	2.36	4.54	11.21	-12.22	4.76	9/29/2010	6/28/2010		
2343	6606	0.80	Snail	2	muscle	3.73	5.17	19.13	-10.26	5.13	9/29/2010	6/28/2010		
2344	6607	0.53	Snail	2	muscle	3.26	4.62	16.18	-11.00	4.97	9/29/2010	6/28/2010		
2345	6608	0.50	Snail	2	muscle	3.11	5.62	16.72	-11.41	5.38	9/29/2010	6/28/2010		
2346	6609	0.98	Mussel	2	muscle	8.63	6.62	34.55	-20.09	4.00	9/29/2010	6/28/2010		
2350	6610	0.36	F.Heteroclitus	3	muscle	3.47	9.42	13.82	-16.31	3.98	9/29/2010	6/28/2010	5	M
2352	6611	0.78	F.Heteroclitus	3	muscle	7.48	9.71	30.71	-16.34	4.11	9/29/2010	6/28/2010	5.2	M
2354	6612	0.62	F.Heteroclitus	3	muscle	5.60	9.03	23.47	-15.54	4.19	9/29/2010	6/28/2010	4.7	M
2356	6613	0.61	F.Heteroclitus	3	muscle	3.76	8.99	15.08	-15.15	4.01	9/29/2010	6/28/2010	5.5	M
2358	6614	0.50	F.Heteroclitus	3	muscle	4.85	9.33	20.23	-15.95	4.17	9/29/2010	6/28/2010	4.8	M
2355	6612	0.52	F.Heteroclitus	3	liver	4.13	8.19	21.81	-15.88	5.28	9/29/2010	6/28/2010		M

2357	6613	0.49	F.Heteroclitus	3	liver	4.05	8.45	20.40	-16.30	5.03	9/29/2010	6/28/2010		M
2353	6611	0.35	F.Heteroclitus	3	liver	2.77	8.93	14.24	-17.60	5.15	9/29/2010	6/28/2010		M
2351	6610	0.75	F.Heteroclitus	3	liver	6.34	8.49	31.40	-16.70	4.95	9/29/2010	6/28/2010		M
2359	6615	0.84	Snail	3	muscle	6.55	4.92	28.99	-13.71	4.42	9/29/2010	6/28/2010		
2360	6616	0.89	Snail	3	muscle	6.72	5.01	31.29	-15.02	4.66	9/29/2010	6/28/2010		
2361	6617	0.75	Snail	3	muscle	5.93	4.87	26.81	-15.11	4.52	9/29/2010	6/28/2010		
2362	6618	0.91	Snail	3	muscle	3.63	4.76	23.62	-13.78	6.52	9/29/2010	6/28/2010		
1819	6619	0.82	F.Heteroclitus	4	muscle	7.93	8.99	30.34	-17.68	3.83	8/11/2010	6/30/2010	7.4	M
1821	6620	0.74	F.Heteroclitus	4	muscle	6.65	9.06	28.67	-18.94	4.31	8/11/2010	6/30/2010	8.4	M
1823	6621	0.89	F.Heteroclitus	4	muscle	8.97	9.19	35.16	-18.66	3.92	8/11/2010	6/30/2010	6.9	M
1825	6622	1.00	F.Heteroclitus	4	muscle	9.93	8.91	40.08	-19.32	4.04	8/11/2010	6/30/2010	6.7	M
1827	6623	0.54	F.Heteroclitus	4	muscle	5.51	9.10	20.83	-17.88	3.78	8/11/2010	6/30/2010	7.3	M
1820	6619	0.76	F.Heteroclitus	4	liver	6.19	8.16	30.98	-18.87	5.00	8/11/2010	6/30/2010		M
1822	6620	0.99	F.Heteroclitus	4	liver	6.52	8.65	40.94	-20.37	6.28	8/11/2010	6/30/2010		M
1824	6621	0.73	F.Heteroclitus	4	liver	4.29	8.14	32.19	-21.33	7.50	8/11/2010	6/30/2010		M
1826	6622	0.37	F.Heteroclitus	4	liver	2.53	8.04	15.42	-21.25	6.11	8/11/2010	6/30/2010		M
1828	6623	0.60	F.Heteroclitus	4	liver	5.27	9.27	24.05	-18.76	4.56	8/11/2010	6/30/2010		M
1829	6624	0.49	F.Heteroclitus	5.2	muscle	4.39	9.17	17.35	-19.20	3.95	8/11/2010	6/30/2010	6.4	M
1831	6625	0.51	F.Heteroclitus	5.2	muscle	4.57	9.00	18.13	-18.16	3.97	8/11/2010	6/30/2010	4.4	M
1832	6626	0.90	F.Heteroclitus	5.2	muscle	8.99	9.49	34.56	-18.88	3.84	8/11/2010	6/30/2010	4.5	M
1837	6627	0.31	F.Heteroclitus	5.2	muscle	3.07	7.94	11.87	-17.94	3.87	8/11/2010	6/30/2010	5.9	F
1839	6628	0.56	F.Heteroclitus	5.2	muscle	5.57	8.81	21.41	-18.22	3.84	8/11/2010	6/30/2010	7.2	F
1841	6629	0.55	F.Heteroclitus	5.2	muscle	5.12	8.54	19.97	-19.18	3.90	8/11/2010	6/30/2010	6	F
1830	6624	0.56	F.Heteroclitus	5.2	liver	4.66	8.64	21.32	-20.26	4.58	8/11/2010	6/30/2010		M
1833	6626	0.33	F.Heteroclitus	5.2	liver	2.77	9.21	13.06	-20.10	4.72	8/11/2010	6/30/2010		M
1838	6627	0.46	F.Heteroclitus	5.2	liver	3.63	7.52	17.40	-18.98	4.80	8/11/2010	6/30/2010		M
1840	6628	0.52	F.Heteroclitus	5.2	liver	3.75	8.16	21.73	-21.01	5.79	8/11/2010	6/30/2010		F
1842	6629	0.81	F.Heteroclitus	5.2	liver	5.49	7.87	29.08	-20.66	5.29	8/11/2010	6/30/2010		F
1843	6630	0.35	Menidia menidia	5.2	muscle	3.03	10.20	11.24	-20.33	3.72	8/11/2010	6/30/2010		M
1844	6630	0.38	Menidia menidia	5.2	liver	3.06	8.55	14.07	-20.14	4.59	8/11/2010	6/30/2010		M
1845	6631	0.55	F.Heteroclitus	6	muscle	5.58	8.94	21.72	-18.87	3.89	8/11/2010	6/28/2010	5.9	M
1847	6632	0.71	F.Heteroclitus	6	muscle	6.87	8.66	27.49	-18.91	4.00	8/11/2010	6/28/2010	6.7	M
1849	6633	0.47	F.Heteroclitus	6	muscle	4.12	8.32	15.66	-18.10	3.80	8/11/2010	6/28/2010	7.5	M
1851	6634	0.41	F.Heteroclitus	6	muscle	4.22	9.16	16.42	-18.95	3.89	8/11/2010	6/28/2010	6.9	M
1846	6631	0.22	F.Heteroclitus	6	liver	2.06	8.10	8.87	-19.85	4.30	8/11/2010	6/28/2010		M

1848	6632	0.31	F.Heteroclitus	6	liver	2.08	7.10	12.59	-20.43	6.05	8/11/2010	6/28/2010		M
1850	6633	0.40	F.Heteroclitus	6	liver	3.55	8.28	16.77	-19.44	4.72	8/11/2010	6/28/2010		M
3478	7817	0.82	F.Heteroclitus	5.2	muscle	7.82	10.21	32.60	-18.89	4.17	11/18/2010	10/30/2010	8.1	F
3481	7818	1.26	F.Heteroclitus	5.2	muscle	12.66	9.59	52.51	-17.83	4.15	11/18/2010	10/30/2010	8.2	F
3483	7819	0.80	F.Heteroclitus	5.2	muscle	7.54	9.47	32.86	-19.55	4.36	11/18/2010	10/30/2010	8.8	F
3482	7820	0.70	F.Heteroclitus	5.2	muscle	6.84	9.77	29.32	-19.60	4.29	11/18/2010	10/30/2010	9.4	F
3479	7821	0.80	F.Heteroclitus	5.2	muscle	7.55	9.19	33.10	-20.00	4.38	11/18/2010	10/30/2010	8.9	F
3484	7818	0.98	F.Heteroclitus	5.2	liver	2.00	8.91	39.17	-21.82	19.56	11/18/2010	10/30/2010		F
3480	7820	1.01	F.Heteroclitus	5.2	liver	2.76	9.36	44.67	-21.77	16.17	11/18/2010	10/30/2010		F
1887	6635	0.30	nereis	1	muscle	2.45	4.80	11.25	-19.49	4.59	8/12/2010	6/30/2010		
1888	6636	0.33	nereis	2	muscle	2.92	5.20	12.53	-17.22	4.29	8/12/2010	6/30/2010		
1889	6637	0.19	shrimp	2	muscle	0.84	2.33	5.60	-17.05	6.69	8/12/2010	6/30/2010		
1890	6638	0.51	nereis	3	muscle	4.34	5.91	20.69	-15.08	4.77	8/12/2010	6/30/2010		
1891	6639	0.70	nereis	5.2	muscle	5.26	3.66	23.09	-19.46	4.39	8/12/2010	6/30/2010		
1892	6640	0.94	nereis	6	muscle	7.43	4.08	36.08	-18.95	4.86	8/12/2010	6/30/2010		
3485	7822	0.00		1	filter	1.26	9.00	8.56	-22.50	6.81	11/18/2010	10/30/2010		
3486	7823	0.00		2	filter	0.75	6.75	3.70	-22.05	4.92	11/18/2010	10/30/2010		
3487	7824	0.00		3	filter	0.84	7.97	4.30	-22.05	5.12	11/18/2010	10/30/2010		
3488	7825	0.00		4	filter	0.39	2.23	3.64	-24.03	9.24	11/18/2010	10/30/2010		
3489	7826	0.00		5.2	filter	0.35	5.74	2.88	-24.34	8.15	11/18/2010	10/30/2010		
3490	7827	0.00		6	filter	0.53	4.27	4.74	-24.08	8.89	11/18/2010	10/30/2010		
1911	7828	0.00		1	filter	2.21	3.43	14.95	-26.25	6.78	8/12/2010	6/4/2010		
1904	7829	0.00		1	filter	0.98	1.23	6.32	-22.08	6.44	8/12/2010	6/29/2010		
1902	7830	0.00		2	filter	1.25	2.01	6.68	-25.30	5.33	8/12/2010	6/29/2010		
1909	7831	0.00		3	filter	1.26	2.77	7.54	-21.37	6.01	8/12/2010	6/29/2010		
1903	7832	0.00		5.2	filter	0.86	7.25	7.10	-21.44	8.23	8/12/2010	6/30/2010		
1910	7833	0.00		6	filter	1.10	7.44	8.29	-21.07	7.51	8/12/2010	6/28/2010		
1860	7834	0.89		1	sediment	0.37	0.59	5.13	-19.70	14.02	8/12/2010	6/29/2010		
1861	7835	0.52		1	sediment	0.29	-0.15	5.44	-20.27	18.67	8/12/2010	6/29/2010		
1862	7836	0.46		1	sediment	0.00	0.00	2.12	-19.99		8/12/2010	6/29/2010		
1863	7837	0.43		2	sediment	0.19	0.25	2.39	-18.96	12.74	8/12/2010	6/29/2010		
1864	7838	0.33		2	sediment	0.53	5.67	4.58	-20.68	8.64	8/12/2010	6/29/2010		
1865	7839	0.50		2	sediment	0.24	1.24	3.05	-19.16	12.95	8/12/2010	6/29/2010		
1866	7840	0.43		3	sediment	0.23	-0.04	2.99	-18.20	13.06	8/12/2010	6/29/2010		
1867	7841	0.40		3	sediment	0.20	0.92	2.56	-19.35	12.81	8/12/2010	6/29/2010		
1868	7842	0.69		3	sediment	0.37	1.11	5.03	-18.11	13.71	8/12/2010	6/29/2010		

1869	7843	0.54	4	sediment	0.71	0.79	6.77	-20.03	9.47	8/12/2010	6/30/2010
1870	7844	0.36	4	sediment	0.38	0.78	6.58	-20.87	17.54	8/12/2010	6/30/2010
1871	7845	0.65	4	sediment	0.99	0.76	12.84	-19.47	13.00	8/12/2010	6/30/2010
1872	7846	0.58	5	sediment	0.80	-0.62	8.46	-20.88	10.62	8/12/2010	6/30/2010
1873	7847	0.56	5	sediment	0.65	0.37	9.33	-20.08	14.40	8/12/2010	6/30/2010
1874	7848	0.52	5	sediment	0.64	0.49	8.43	-20.30	13.21	8/12/2010	6/30/2010
1878	7849	0.73	5.2	sediment	0.65	2.02	8.34	-21.14	12.74	8/12/2010	6/30/2010
1879	7850	0.91	5.2	sediment	0.65	2.23	8.76	-18.43	13.52	8/12/2010	6/30/2010
1880	7851	0.60	5.2	sediment	0.64	1.79	10.54	-22.84	16.51	8/12/2010	6/30/2010
1881	7852	0.77	6	sediment	0.57	2.04	8.75	-17.30	15.48	8/12/2010	6/30/2010
1882	7853	0.52	6	sediment	0.44	1.42	6.95	-20.00	15.95	8/12/2010	6/30/2010
1883	7854	0.56	6	sediment	0.55	1.89	7.59	-19.50	13.73	8/12/2010	6/30/2010
1884	7855	0.42	3	veg	0.45	2.38	10.11	-19.69	22.58	8/12/2010	7/15/2010
1885	7856	0.69	5.2	veg	1.86	0.95	16.08	-18.35	8.67	8/12/2010	7/14/2010
1886	7857	0.41	4	veg	0.72	-1.61	11.77	-15.26	16.46	8/12/2010	7/20/2010

Appendix A: All of the raw isotopic data recorded during this work. The BCID is the Bates College Identification number on the sample run through the IRMS.

Appendix B

Date Collected	Site	Type of Fish	Sex	Fish Number	Total	Weight (g)	Length (cm)	Stom.Wgt (g)	%worm	%veg	%animal	%other	% mite	d13C muscle	d15N muscle
6/3/2006	1	*F. heteroclitus*	M	1		1.341	5.3	2.786	50.00	50.00				-16.92	8.84
6/3/2006	1	*F. heteroclitus*	M	2	7	2.33	5.7	n/a	40.00	60.00				-17.88	8.91
6/3/2006	1	*F. heteroclitus*	M	3	5	1.549	4.9	0.087	80.00	20.00				-17.49	8.77
6/3/2006	1	*F. heteroclitus*	M	4	7	1.328	4.9	0.14	28.57	71.43				-16.42	8.94
6/3/2006	1	*F. heteroclitus*	M	5	5	1.336	4.7	0.087		60.00		40.00		-17.89	9.04
6/3/2006	1	*G. aculeatus*	M	1	3	1.622	6.2	0.065	100.00					-19.46	11.71
6/3/2006	1	*G. aculeatus*	F	2	5	3.12	6.9	0.089		20.00	80.00			-18.79	11.25
6/3/2006	1	*G. aculeatus*	F	3	34	2.601	6.4	n/a				100.00		-18.52	11.12
6/3/2006	1	*G. aculeatus*	M	4	65	1.426	5.8	0.093				100.00		-20.27	10.01
6/3/2006	1	*G. aculeatus*	M	5	18	1.601	5.9	0.126			16.67	83.33		-19.74	11.58
6/28/2010	2	*F. heteroclitus*	M	1	6	1.614	5.1	0.094		100.00				-15.01	9.02
6/28/2010	2	*F. heteroclitus*	M	2	6	2.002	5.4	0.131		100.00				-15.85	9.20
6/28/2010	2	*F. heteroclitus*	M	3	7	2.156	5.4	0.098		85.71		14.29		-16.56	9.57
6/28/2010	2	*F. heteroclitus*	M	4	8	2.179	5.6	0.107		100.00				-17.14	9.60
6/28/2010	2	*F. heteroclitus*	M	5	8	1.601	5.3	0.059		75.00	25.00			-16.64	8.68
6/28/2010	3	*F. heteroclitus*	M	1	8	1.31	5	0.029		50.00	50.00			-16.31	9.42
6/28/2010	3	*F. heteroclitus*	M	2	9	1.593	4.7	0.042			100.00			-16.34	9.71
6/28/2010	3	*F. heteroclitus*	M	3	15	1.201	4.7	0.042		33.33	66.67			-15.54	9.03
6/28/2010	3	*F. heteroclitus*	M	4	8	1.962	5.5	0.9		75.00	25.00			-15.15	8.99
6/28/2010	3	*F. heteroclitus*	M	5	14	1.236	4.8	0.041					100.00	-15.95	9.33
6/30/2010	4	*F. heteroclitus*	M	1	5	7.002	7.4	0.223		60.00	40.00			-17.68	8.99
6/30/2010	4	*F. heteroclitus*	M	2	9	7.161	8.4	0.243		77.78	22.22			-18.94	9.06
6/30/2010	4	*F. heteroclitus*	M	3	7	4.412	6.9	0.125		71.43	28.57			-18.66	9.19
6/30/2010	4	*F. heteroclitus*	M	4	8	6.624	6.7	0.377		75.00	25.00			-19.32	8.91
6/30/2010	4	*F. heteroclitus*	M	5	5	5.087	7.3	0.157		80.00		20.00		-17.88	9.10
6/30/2010	5.2	*F. heteroclitus*	M	1	4	3.817	6.4	0.113		75.00		25.00		-19.20	9.17
6/30/2010	5.2	*F. heteroclitus*	M	2	2	0.989	4.4	0.043		100.00				-18.16	9.00
6/30/2010	5.2	*F. heteroclitus*	M	3	5	1.142	4.5	0.051		80.00	20.00			-18.88	9.49
6/30/2010	5.2	*F. heteroclitus*	F	4	6	2.906	5.9	0.125		66.67	33.33			-17.94	7.94
6/30/2010	5.2	*F. heteroclitus*	F	5	9	4.389	7.2	0.28		11.11		88.89		-18.22	8.81
6/30/2010	5.2	*F. heteroclitus*	F	6	6	2.623	6	0.061		33.33	66.67			-18.22	8.54
6/30/2010	5.2	*M. menidia*	M	7	3	0.738	5.9	0.027		66.67	33.33			-20.33	10.20
10/30/2006	5.2	*F. heteroclitus*	F	1	3	6.561	8.1	0.225	33.33		66.67			-18.89	10.21
10/30/2006	5.2	*F. heteroclitus*	F	2	3	6.898	8.2	0.288		66.67	33.33			-17.83	9.59

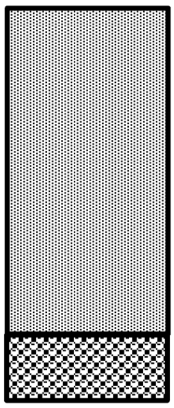
10/30/2006	5.2	*F. heteroclitus*	F	3	5	9.807	8.8	0.448	60.00	40.00		-19.55	9.47
10/30/2006	5.2	*F. heteroclitus*	F	4	7	11.455	9.4	0.466	57.14	28.57	14.29	-19.60	9.77
10/30/2006	5.2	*F. heteroclitus*	F	5	7	9.934	8.9	0.295	28.57	57.14	14.29	-20.00	9.19
6/28/2010	6	*F. heteroclitus*	M	1	13	3.086	6.7	0.136	61.54	15.38	23.08	-18.87	8.94
6/28/2010	6	*F. heteroclitus*	M	2	13	2.049	5.8	0.63	30.77	46.15	23.08	n/a	n/a
6/28/2010	6	*F. heteroclitus*	M	3	32	5.353	7.5	0.179	7.41	9.38	84.38	-18.91	8.66
6/28/2010	6	*F. heteroclitus*	M	4	23	4.926	6.9	0.246	17.39	26.09	56.52	-18.10	8.32
6/28/2010	6	*F. heteroclitus*	M	5	16	2.168	5.5	0.113	25.00	25.00	50.00	-18.95	9.16

Appendix C

Natural Pool Sites Core Stratigraphy

Site 1

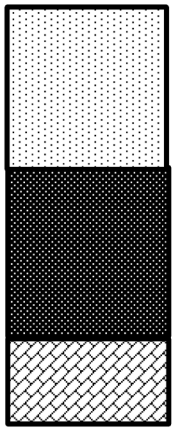
Depth; Munsell Color; Description



0-9.5cm; 10 YR 4/2 (Dark greyish brown); Organic; Sand present: high in muscovite; few fine roots present

9.5-12cm; 10 YR 3/2 (Very dark brown); Highly organic; sandy; coarse roots

Site 2

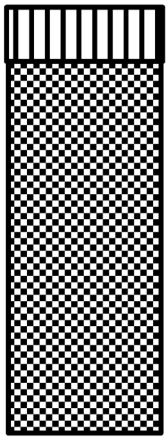


0-6cm; 10 YR 4/2 (Dark greyish brown); Sandy; organic

6-12cm; 10 YR 4/2 (Dark greyish brown); Fine roots; sandy

12-16cm; 10 YR 3/2 (Very dark greyish brown); Sandy; coarse roots

Site 3



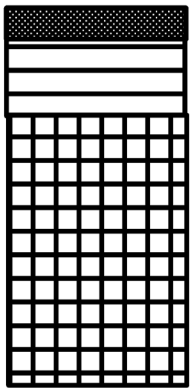
0-2cm; 10 YR 4/2 (Dark greyish brown); Fine grained sand; organic

2-17cm; 10 YR 3/2 (Very dark greyish brown) Large Spartina alterniflora roots;peat

Ditchplug Pool Sites Core Stratigraphy

Depth; Munsell Color; Description

Site 4

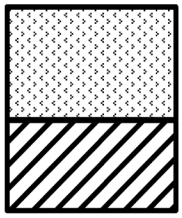


0-1cm; 10 YR 2/1(Black); Highly organic; fine grained, few fine roots

1-3cm; 10 YR 3/2 (Very dark greyish brown); Fine roots, organic

3-11cm; 10YR 2/2 (Very dark brown); Coarse roots from Spartina alterniflora with some fine roots

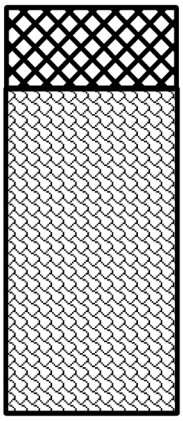
Site 5.2



0-3 cm; 5Y 3/2 (Very dark grey); fine roots of Spartina patens or Maritima ruppia

3-5.5 cm; 5Y 2.5/1 (Black); fine grained highly organic sediment with fine roots of Spartina patens or Ruppia maritima

Site 6



0-2.5cm; 10YR 3/1 (Very dark grey); Spartina patens roots and fine grained sediment

2.5-8.5cm; 10YR 2/1 (black); Spartina patens and Spartina alterniflora roots, silt/clay sediment, highly organic